# DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-76-1

# MATHEMATICAL MODEL FOR PREDICTING THE CONSOLIDATION OF DREDGED MATERIAL IN CONFINED DISPOSAL AREAS

by

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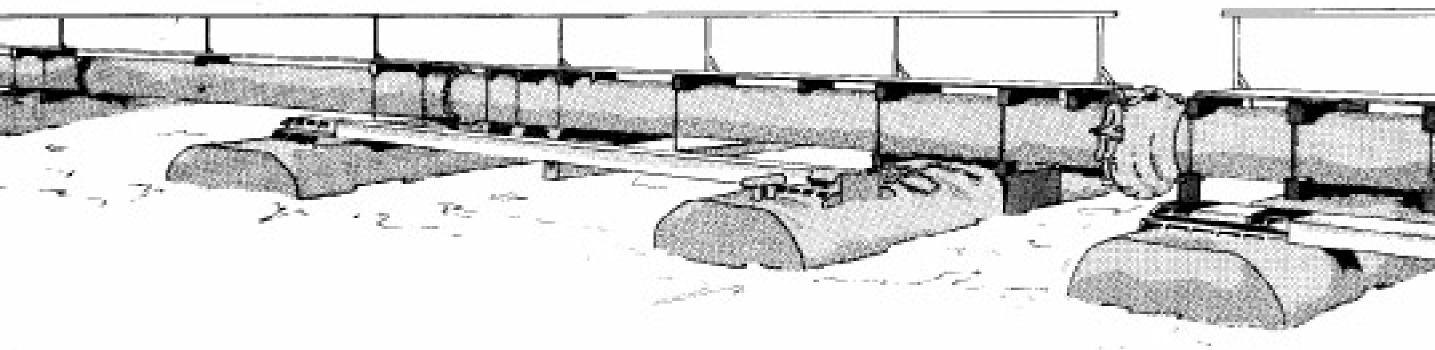

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SUBJECT: Transmittal of Technical Report D-76-1

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1. The contract report transmitted herewith represents the results of one research effort (work unit) initiated as part of Task 2C (Containment Area Operations Research) of the Corps of Engineers' Dredged Material Research Program (DMRP). Task 2C is included as part of the Disposal Operations Project of the DMRP, which, among other considerations, includes research into various ways of improving the efficiency and acceptability of facilities for confining dredged material on land.

2. Confining dredged material on land is a relatively recent disposal alternative to which practically no specific design or construction improvement investigations, much less applied research, have been addressed. There has been a dramatic increase in the last several years in the amount of land disposal necessitated by confining dredged material classified as polluted. This has resulted in the design of major facilities based on "rules of thumb" or previous experience and without exact engineering procedures for determining the actual volume of containment area required to confine given volumes of dredged material over given periods of time. Attention is necessarily directed toward eliminating this design deficiency as part of the DMRP.

3. DMRP work units are in progress investigating current facility design and construction practices. It is obvious that in order to determine the capacity of a containment facility, the sedimentation process of the dredged material and the sedimentation and consolidation processes of both the dredged material and foundation material must be understood and modeled. As a first step in accomplishing these goals, the investigation reported herein was undertaken by the Soils and Pavements Laboratory of the U. S. Army Engineer Waterways Experiment Station.

4. The study identified and evaluated important parameters related to sedimentation and consolidation influencing determination of containment area capacities; interim guidelines are suggested for sizing on the basis

of current knowledge and research. The guidelines are deficient to the extent that they are by no means considered to be a final design procedure. The deficiencies of the guidelines result from the lack of current knowledge of and research on soil mechanics concepts of the problem as well as factors resulting from operational and management practices at containment areas.

5. This study is considered to be an important and necessary first step in developing a sound engineering approach for determining the capacities of containment areas. The results of the study will be used to identify the research needs for a work unit presently underway to develop a design procedure for determining the capacity of a containment area. Other work being conducted under this task, as well as Tasks 5A and 5C, is providing information to fill the gaps resulting from the lack of understanding of the effects of operational and management practices on the overall problem.

G. H. HILT
Colonel, Corps of Engineers
Director

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The capacity of containment areas is influenced by many factors that include: (a) variations in material being dredged; (b) type of dredge; (c) volume change on handling the dredged material while dredging and during deposition; (d) flow velocities of the dredged slurry in the area; (e) elimination of carrying water by runoff through weirs; (f) solids in the effluent; (g) soil permeabilities; (h) flow patterns and seepage

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through dikes; (i) primary consolidation; and (j) secondary compression effects. Current methods for estimating the capacity of containment areas for placement of dredged material often rely on empirical factors and local experience. From an investigation of various methods for sizing containment areas, suggestions are made for estimating containment area capacity based on consolidation of the dredged material and foundation soils.

The capacity of a containment area is defined herein as the total volume of the diked area available to hold dredged material. It is equal to the total unoccupied volume minus the volume associated with the freeboard. The capacity required to accommodate a given volume of in situ sediment to be dredged is related to the volume change characteristics of the sediment. For instance, the volume of sands and gravels deposited in the containment area usually does not change significantly with time and often is the same as, or only moderately more than, that of the in situ material. In contrast, the volume of silts and clays usually increases substantially on dredging and deposition. The subsequent consolidation of these materials can be substantial and lead to significant increases in space available in the containment area for placement of additional dredged material.

The volume-time relationships of dredged material are important in predicting the capacity of containment areas and also have considerable impact on subsequent use of deposition areas. Reasonably reliable estimates of the capacity require knowledge of the solids in the effluent water and evaluation of the time rate of change in void ratio of dredged material as it consolidates in the containment area. The usual containment area design does not consider time effects, but uses an empirical bulking factor that relates the volume of in situ sediments to the volume required in the containment area to place the same material. Experience indicates that bulking factors for this purpose vary from about one for most granular materials to as high as two for some fine materials, depending on local conditions. Values below one can occur for loose, granular material or fluffy, fine-grained deposits.

A tentative procedure is suggested for the estimation of the volume-time relationships of dredged material in a flooded containment area based on simple sedimentation and consolidation theories. The procedure also includes a method to compute the consolidation of the foundation soils by standard consolidation theory. Laboratory and field investigations are necessary to verify and to develop further the equations and procedures obtained during this study for estimating volume changes with time of various types of sediments accommodated in containment areas. These factors will be investigated in subsequent Dredged Material Research Program studies in order to develop a complete methodology for determining the capacity of a containment area.

PREFACE

The study reported herein was performed at the U. S. Army Engineer Waterways Experiment Station (WES) under in-house contract, Work Unit 2C08, "Development of Guidelines for Containment Area Design," dated 4 June 1973, between the Environmental Effects Laboratory (EEL) and the Soils and Pavements Laboratory (S&PL). The research was sponsored by the Office, Chief of Engineers (DAEN-CWO-M), under the Civil Works Dredged Material Research Program (DMRP) being planned and implemented by EEL. This study was part of the DMRP Disposal Operations Research Project, Mr. C. C. Calhoun, Jr., Manager.

The work was conducted during the period June 1973-June 1974 by Dr. L. D. Johnson, Research Group, Soil Mechanics Division (SMD), S&PL, under the general supervision of Messrs. J. P. Sale, Chief of S&PL, and C. L. McAnear, Chief of SMD. Mr. S. J. Johnson, Special Assistant, S&PL, provided especially helpful suggestions and advice. The study also benefited greatly from valuable assistance given by Messrs. R. G. Ahlvin, C. L. McAnear, and W. C. Sherman, Jr., S&PL; and Messrs. R. L. Montgomery, N. C. Baker, and CPT W. C. Allanach, Jr., EEL. This report was prepared by Dr. Johnson.

Directors of the WES during the conduct of the study and preparation of this report were BG E. D. Peixotto, CE, and COL G. H. Hilt, CE. The Technical Director was Mr. F. R. Brown.

CONTENTS

## CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| inches | 2.54 | centimetres |
| feet | 0.3048 | metres |
| yards | 0.9144 | metres |
| square inches | 6.4516 | square centimetres |
| square feet | 0.09290304 | square metres |
| square yards | 0.8361274 | square metres |
| cubic feet | 0.02831685 | cubic metres |
| cubic yards | 0.07645549 | cubic metres |
| pounds (mass) | 0.4535924 | kilograms |
| pounds (force) per square inch | 6.894757 | kilopascals |
| pounds (mass) per cubic foot | 16.01846 | kilograms per cubic metre |
| Fahrenheit degrees | 5/9 | Celsius degrees or Kelvins* |

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

# MATHEMATICAL MODEL FOR PREDICTING THE CONSOLIDATION OF DREDGED MATERIAL IN CONFINED DISPOSAL AREAS

## PART I: INTRODUCTION

### Background

1. Large volumes of material must be dredged each year from navigable waterways and harbors to permit economical and efficient operation of waterway transportation systems. Some dredged material is placed on land or in water in containment areas of various types, while some is deposited in open water. In the past, open-water disposal was by far the most common procedure, but confined containment areas are becoming increasingly important, particularly for disposal of materials considered polluted. Disposal in confined areas or on land is also sometimes preferred to open water for economic reasons.[1]

2. Growing population and industrial development are rapidly reducing the availability of land for disposal areas and thus are contributing to the high costs for purchase or lease of new sites. The increasing costs associated with the difficulty of finding and developing appropriate containment areas necessitate maximum use of available areas for disposal of dredged material. In many instances, it may be desirable to design and operate containment areas in such a way that the areas will make satisfactory sites for multiple purposes such as locations for recreational parks, harbor facilities, residential areas, and industrial centers when the useful life of the disposal area is complete.

3. Two important factors in optimizing the design and operation of confined disposal areas for dredged material are: (a) the ability to estimate accurately the volume required in the containment area to accommodate the volume of in situ materials to be dredged; and (b) the methodology to predict the rate at which space will become available for placement of additional dredged material due to reduction in water content by removal of free water over weirs, seepage through dikes,

etc., and consolidation of the dredged sediment and foundation soils. Information of this nature will contribute toward efficient use of dredges and containment areas and improved scheduling of the use of adequate containment areas at proper times. Effective systematic disposal procedures may also aid in development of better soil foundation conditions in areas to be used for other purposes at some later date. Advance plans could thereby be prepared for appropriate use of the site.

4. Current procedures for estimating the volume of in situ material that can be accommodated in a containment area are not well documented and tend to be based on previous local experience. A common method is to apply bulking factors that, multiplied by the volume of material to be dredged, determine the required volume of the containment area. Procedures to determine the bulking factor are not standardized and proper guidelines are thus not available for estimating disposal area capacities. Many U. S. Army Corps of Engineers District offices include a clause in their dredging specifications that requires the contractor to cease disposal operations in the event of dike failures or if freeboard or effluent quality requirements are not met. These situations indicate that sufficient storage capacity may not have been provided.[2] A critical need exists for adequate guidelines for the estimation of containment area capacity to store a specific slurry of dredged material.

## Purpose and Scope

5. The purpose of this study was to evaluate important parameters related to sedimentation and consolidation influencing determination of containment area capacity and to suggest guidelines for such sizing on the basis of current knowledge and research. The guidelines were to include uniform and reasonable procedures for estimating the volume required in the containment area to hold dredged material, as well as to determine the density of the resulting fill. Emphasis was placed on developing procedures for estimating additional volume later available due to consolidation of the dredged material and underlying

foundation soils of the containment area. The findings of the study were applied to the analysis of the size requirements for an example containment area. Deficiencies of current procedures and needs for further research are outlined herein.

## PART II: CAPACITY OF CONTAINMENT AREAS

6. The capacity of a containment area is defined herein as the total volume of the diked area available to hold dredged material. It is equal to the total unoccupied volume minus the volume associated with the freeboard. The capacity of a containment area required to accommodate the entire sediment from a dredging operation depends on the total volume of material to be dredged including the volume from overdredging. Overdredged material is characterized as all material removed in excess of the volume specified or required for removal.

7. The problem of determining the capacity of a containment area is complicated by many factors that include: (a) variation in material being dredged; (b) type of dredge; (c) volume change on handling the dredged material while dredging and during deposition; (d) elimination of carrying water by runoff through weirs, filters, and outlet channels; (e) solids in the effluent; (f) effect of permeabilities and flow patterns on seepage; (g) seepage through dikes and underlying aquifers; (h) effect of horizontal flow velocities in the containment area; (i) rate of input of dredged material into the containment area; (j) consolidation (which may be treated by conventional theories, laboratory tests, and sophisticated three-dimensional analyses); and (k) secondary compression phenomena. The current study was necessarily restricted to simple analyses in an attempt to obtain a tentative procedure for an approximate evaluation of the volume-time relationships of dredged material and foundation soils in flooded containment areas. Bulking factors are initially discussed to outline current procedures for estimating the ultimate reduction in volume of dredged material and to add to the understanding of the relative behavior of different types of dredged material. Volume-time relationships are explored by examination of sedimentation and consolidation theories.

### Bulking Factors

8. A bulking factor has been commonly used for estimation of

required containment area capacity to accommodate a specific dredged material. With a given weight of solids, the bulking factor of a sediment is a simple ratio of the volume occupied by the sediment after sedimentation in the containment area to the volume of the in situ material before dredging

$$B^* = \frac{V_{ca}}{V_{in}} \tag{1a}$$

or

$$B = \frac{\gamma_d in}{\gamma_d ca} \tag{1b}$$

or for saturated conditions

$$B = \frac{w_{ca} G_s + 100}{w_{in} G_s + 100} \tag{1c}$$

where

$B$ = bulking factor

$V_{ca}$ = volume of dredged material after sedimentation in the containment area, $L^3$

$V_{in}$ = total volume of in situ material to be dredged, $L^3$

$\gamma_d in$ = dry density of in situ material, $ML^{-2}T^{-2}$

$\gamma_d ca$ = dry density of sediment in the containment area, $ML^{-2}T^{-2}$

$w_{ca}$ = water content of sediment in the containment area, percent

$G_s$ = specific gravity of dredged material

$w_{in}$ = water content of in situ material to be dredged, percent

9. A soil with a low in situ density may be assigned a relatively small bulking factor (such as one or less), while a similar type of soil with a greater in situ density may be assigned a bulking factor that is greater than one. Bulking factors for certain types of sediments and for specific locations have consequently been determined on

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* For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix C).

the basis of data accumulated from prior disposal operations and experience for application in evaluation of the capacities of containment areas required for future disposal operations. For the dredged material encountered in the United States (Table 1), bulking and design factors are given in Tables 2 and 3. The design factor is defined as a bulking factor that has been increased to include an allowance for overdredging or altered to consider ponding time or the efficiency $E$ of the disposal operation. The bulking or design factors according to region (Table 2) are based on local experience and vary from 0.5 to 2.0 depending on the type of in situ soils. Table 3 compares the ratio of the dry densities of some common in situ soils[10] with the dry densities of clay, silt, and sand sediments.[11] These density ratios yield bulking factors from Equation 1 that usually agree well with bulking factors from Reference 12.

10. The efficiency of a containment area $E$ is defined as the relative amount of solids retained by the containment area and can be expressed by

$$E = \left( \frac{F_i - F_o}{F_i} \right) 100 \tag{2}$$

where

$F_i$ = fraction of solids in input slurry by weight, percent

$F_o$ = fraction of solids in discharge effluent by weight, percent

11. The discharge effluent is ponded water released from the containment area, usually by flow over a weir. The efficiency for retaining fine sediment containing colloidal particles may easily be much less than the retention efficiency for sand. The required efficiency of the containment area is usually determined from water-quality standards. A reliable estimation of the actual efficiency of the containment area prior to the disposal operation can be difficult and is the subject of current research as part of the Dredged Material Research Program (DMRP).

12. The variation in bulking factors and types of sediment shows

that some exploratory study of the bottom materials to be dredged is required to decide on a bulking factor for local dredging operations. Evaluation of accurate in situ dry densities of sediment can be difficult due to sample disturbance and the existence of water and fast-moving currents above the sediment to be dredged. Methods of estimating in situ properties of predredged sediment include past experience, penetration tests,[13] undisturbed sampling,[14] density and moisture readings from nuclear probes,[15] and geophysical explorations.

## Changes in Capacity with Time

13. Sand settles relatively rapidly and reaches an end-point density quickly,[11,16,17] while fine-sized particles such as silt and clay settle and consolidate more slowly.[11,16,18-20] Since most soil contains at least some fine particles and significant amounts of dredged material contain substantial quantities of clay and silt (Table 1), sedimentation and consolidation characteristics of fine sediments need to be known for reliable sizing of containment areas for various types of dredged material and input rates. An understanding of sedimentation and consolidation of fine sediment requires reference to theories of settling velocity and primary consolidation.

14. A knowledge of the development and dissipation of excess pore water pressures in the accumulating sediment is necessary for proper application of consolidation theories. Excess pore water pressures are water pressures in the voids between particles of materials in excess of the steady-state[21] or hydrostatic head.[22] The total positive pore water pressure is the sum of the excess plus steady-state water pressures. Water pressure measurements have shown that excess pore water pressures develop in the sediment layers during bed formation.[23,24] The excess pore water pressures in deposited sediment result from the submerged weight of newly deposited material. The permeability of the sediment must be sufficiently small to restrict dissipation of excess pore water pressures through the surface of the freshly deposited material or through underlying foundation soils. Because of some

dissipation after excess pore water pressures start to build up, primary consolidation (the consolidation from dissipation of excess pore water pressures) may start soon after placement of the dredged material in the containment area.

Settling characteristics of dredged suspensions

15. The settling velocities of fine particles such as silt and clay are influenced by many factors including characteristics and concentration of solids in the slurry, degree of flocculation, and time duration of settling. Settling characteristics of dredged material are particularly difficult to predict because of variations in soil types within a given project or disposal operation. The form that the sediment will take after it is dredged is also difficult to predict; e.g., a clayey dredged material may be in the form of clay balls or a slurry of highly dispersed individual particles.

16. Flocculated masses of particles will settle more rapidly than the individual particles. The amount of flocculation is influenced by the concentration of soluble salts, type of clay mineral, and the turbulence. Increasing the concentration of soluble salts intensifies the amount of flocculation up to some limiting concentration.[24,25] Above the limiting concentration, variation in salt concentration has little effect. Multicharged cations such as aluminum, thorium, calcium, and magnesium are much more effective flocculating agents than single-charged ions such as sodium.[16,24] The multivalent ions suppress the repulsive shield of forces surrounding the individual clay particles such that the short-range Van der Waal attractive forces become more effective and increase bonding between the individual particles. As turbulence intensifies, flocs also tend to become larger because the number of collisions between particles increases, thus bringing more particles together.[25] However, beyond a certain turbulence, the higher shear stresses tend to break down and redisperse the flocculated sediments.

17. In addition to the above effects of flocculation, settling velocities increase with concentration of solids up to a certain limit and then decrease with increasing concentration.[24,25] For suspensions

of less than 10,000 parts per million (about 2.7 percent solids by weight), increasing concentrations augment the settling velocity of various sediments because interference, due to increased interparticle collisions, results in larger flocs.[24] For slurries of higher concentrations such as in the range of dredged slurries (i.e., 10 to 30 percent solids by weight), the settling velocity will decrease for increasing concentration of solids. The flocs in these slurries are brought closer together with increasing concentration. The solids tend to form a continuous network through which water must escape;[24,25] therefore, small excess pore water pressures conceivably may develop in these sediments during the terminal period of sedimentation.

18. Settling velocities of suspensions possessing a range of particle sizes will decrease with time partly because the larger particles or flocs settle to the bed more quickly. As a suspension becomes more dilute, collisions between the remaining smaller-size particles and flocs decrease, and further flocculation and settling are retarded.

Evaluation of sedimentation

19. Bosworth's method. An empirical approach for calculation of the rate of sediment volume change with time taken by Bosworth[26] can be represented as

$$e = e_\infty + \underline{k}\,\frac{(1 + e_\infty)}{t} \tag{3}$$

where

$e$ = void ratio

$e_\infty$ = ultimate void ratio

$\underline{k}$ = constant, T

$t$ = time, T

20. The constant $\underline{k}$ is a complicated factor that is a function of the type of soil, dissolved salts in the water, initial depth, initial void ratio, and testing conditions. The ultimate void ratio $e_\infty$ and the constant $\underline{k}$ may be evaluated from laboratory sedimentation tests by plotting the void ratio $e$ versus $1/t$ and noting that the intercept for $1/t$ equal to zero is $e_\infty$ and the slope is $\underline{k}(1 + e_\infty)$ .

The initial void ratio is not considered in this approach.

21. Equation 3 is useful for calculating intermediate void ratios for time $t > 0$ and for time prior to primary consolidation or consolidation from dissipation of excess pore water pressure. Tests to determine the constant $k$ should closely duplicate field conditions.

22. Practical application of this method may be possible with a laboratory sedimentation test to determine a laboratory value for the constant $k$ and design charts to convert the laboratory $k$ value to a field $k$ value. Design charts for specially defined field conditions may possibly be developed from comparisons of laboratory sedimentation tests with sedimentation observed in the field.

23. New method for determining sedimentation. A solution for the prediction of void ratio changes with time during sedimentation was developed during this study by first determining the settling velocity of fine sediment particles as a function of the void ratio or porosity subject to limitations of Stokes's law. Void ratio changes of the sediment with time can then be found by application of the continuity condition. The results of this analysis (Appendix A) indicated an equation of the form

$$e = \frac{\alpha}{t^{\tau} + \frac{\alpha}{e_{os}}} \tag{4}$$

where

$e$ = void ratio at time $t$

$\alpha = \dfrac{3.15 \times 10^{-6} D}{d_{50}^{2.15}} = \dfrac{\alpha_o D}{d_{50}^{2.15}}$ , days

$\alpha_o$ = constant

$t$ = time from the initial void ratio $e_{os}$ , days

$\tau$ = constant approximately equal to one

$D$ = initial depth of slurry, ft

$d_{50}$ = average diameter of the sediment particles, mm

24. The particle diameter at which 50 percent of the particles are finer by weight, $d_{50}$ , is assumed as an average particle diameter

for calculation of the $\alpha$ parameter (Equation 4). The reliability of this assumption has not been determined. The values of $\alpha_o$ and $\tau$ are dependent on a variety of factors such as fluid viscosity, specific gravity of the solid and liquid phases, concentration and type of dissolved salts, and turbulence. The $\alpha$ and $\tau$ parameters can be empirically evaluated from laboratory sedimentation tests by plotting $\log (1/e - 1/e_{os})$ versus $\log t$ and noting that the intercept at $\log t$ equal to zero is $\log 1/\alpha$ and the slope is $\tau$. The sedimentation tests need not exactly duplicate the initial void ratio and depth of slurry in the containment area.

25. Equation 4 is useful for calculating void ratio changes with time from initial sedimentation and for a depth of slurry D equal to a constant. Solutions of void ratio changes with time for more complicated cases (e.g., for disposal operations that cause the depth of slurry D to increase with time or for cases when slurry is added while effluent is simultaneously discharged over a weir) require more sophisticated boundary conditions in the analysis (Appendix A). These cases are not considered in this relatively elementary analysis.

26. The thickness of the sedimented layer H after sedimentation from a void ratio of $e_{os}$ to $e$ may be given by

$$H = \frac{D(1 + e)}{1 + e_{os}} \tag{5}$$

27. Comparison of methods. Some laboratory measurements made by other investigators of the heights of the sediment versus time were applied to Equation 4 to evaluate the $\alpha_o$ and $\tau$ parameters from experimental data. These sedimentation tests were performed in cylinders or tubes where (a) water flow velocities were not significant; (b) solid concentrations may not have been comparable to solid concentrations of the dredged material input into the containment area; (c) the sides of the cylinder may have exerted some drag on the settling particles; and (d) other factors discussed earlier may not have been comparable to field conditions. The results of this evaluation given in the

tabulation below showed $\alpha_o$ values that varied from $1.6 \times 10^{-6}$ to $10.7 \times 10^{-6}$, which compares favorably with the theoretical value of $3.15 \times 10^{-6}$ used in Equation 4. The $\tau$ values are also reasonably close to the expected value of about one.

| $d_{50}$, mm | D, ft* | $\tau$ | $\alpha$, days | $\alpha_o$ | Source of Data Reference No. |
|---|---|---|---|---|---|
| 0.0014 | 1.5 | 0.6 | 22.0 | $10.7 \times 10^{-6}$ | 27 |
| 0.008 | 3.3 | 0.9 | 0.2 | $1.8 \times 10^{-6}$ | 28 |
| 0.008 | 3.3 | 1.0 | 1.0 | $9.5 \times 10^{-6}$ | 29 |
| 0.004 | 3.3 | 0.9 | 0.7 | $1.6 \times 10^{-6}$ | 30 |

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

28. The experimental curve of sample C22TO (from Reference 27) was plotted in Figure 1 and compared with the curve calculated by the new method with the above experimentally evaluated parameters and an initial void ratio $e_{os}$ of 12.5. The $e_{os}$ was determined from the given initial water content of 470 percent and an assumed specific gravity of solids of 2.65. The original thickness D of this sediment was 1.5 ft. The calculated e-log t relationship (Equation 4) is consistent with the experimental curve. Comparison of the experimental curve with the curve calculated by Bosworth's method (Equation 3) is not as favorable for sample C22TO. The ultimate void ratio $e_\infty$ calculated by Bosworth's relation from the sedimentation test for sample C22TO is about 2.3 or an ultimate dry density of about 50 lb/cu ft.

29. Current theories do not allow calculation of the time and void ratio at which sedimentation is essentially complete and primary consolidation becomes dominant. Figure 1 indicates an inflection point in the sedimentation curve beyond which the rate of decrease in sediment volume is substantially less than that preceding the inflection point. The inflection point may be a rough indication of the void ratio

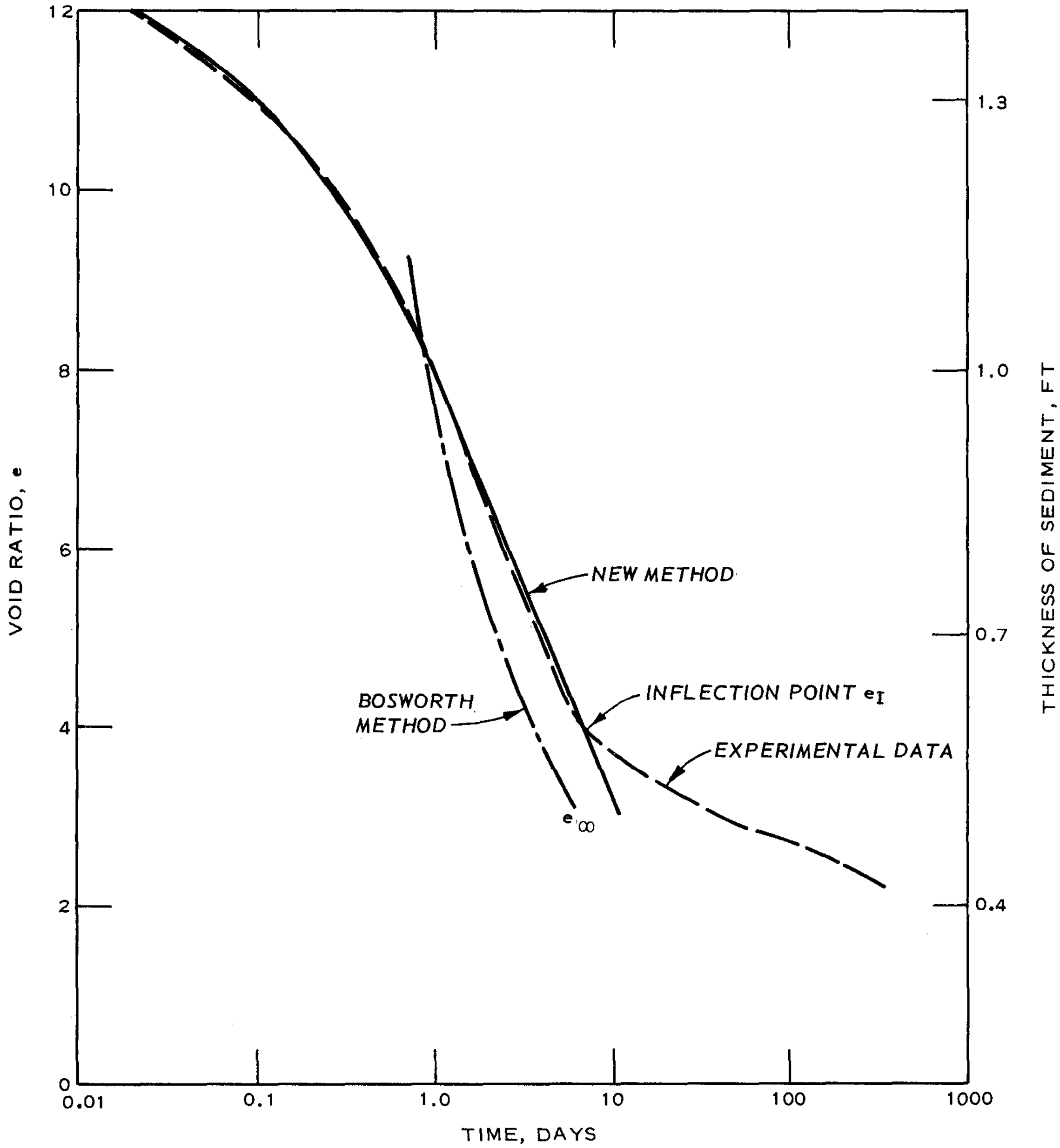



Figure 1. Comparisons of calculated curves with experimental sedimentation curve (sample C22T0, Reference 27)

(denoted as $e_I$) and time at which the sedimentation process can be viewed as completed and normal consolidation commences.

Consolidation characteristics of dredged material and foundation soils

30. Containment dikes and deposited dredged material will exert

surcharge pressures on the foundation soils and promote consolidation of the underlying soils. The settled dredged material will also be subject to consolidation. Terzaghi[31] developed a mathematical expression for the rate at which consolidation may occur from the release of water under pressure. This process is referred to as primary consolidation and differs from secondary compression, which occurs without appreciable change in pore water pressure. Predictions of settlements from solutions of the one-dimensional (1-D) equation for primary consolidation have not always correlated well with actual field settlements.[21,32] Causes for disagreement between predicted and actual settlements include changes in the coefficient of consolidation $c_v$ with the degree of consolidation, multidimensional nature of consolidation, and settlement from secondary compression. Settlement from secondary compression may be substantial compared with settlement from primary consolidation if the stress increment or the magnitude of the excess pore water pressures to be dissipated is initially small. Some foundation soils, particularly soft clay, may fail by shear or creep from the pressure of overlying dredged material. Horizontal displacements from soil creep can lead to settlements not predicted by consolidation theory. This latter problem is not considered a major factor in the sizing of most containment areas, although it may control retaining dike design.

31. Primary consolidation is briefly described as the consolidation of a soil mass resulting from the dissipation of positive excess pore water pressures as water flows from the soil. For 1-D consolidation,

$$\frac{\partial u}{\partial t} = c_v \frac{\partial^2 u}{\partial x^2} \tag{6a}$$

$$c_v = \frac{k}{\gamma_w m_v} \tag{6b}$$

$$m_v = - \frac{\Delta e}{(1 + e_o)\Delta\bar{\sigma}_v} \quad (6c)$$

where

$u$ = total or excess pore water pressure, $ML^{-1}T^{-2}$

$c_v$ = coefficient of consolidation, $L^2T^{-1}$

$x$ = vertical dimension, $L$

$k$ = coefficient of permeability, $LT^{-1}$

$\gamma_w$ = unit weight of water, $ML^{-2}T^{-2}$

$m_v$ = coefficient of volume change, $M^{-1}LT^2$

$\Delta e$ = change in void ratio

$e_o$ = initial void ratio

$\Delta\bar{\sigma}_v$ = change in effective stress, $ML^{-1}T^{-2}$

32. Either the total or excess pore water pressure may be evaluated at any time $t$ as a function of depth $x$ from solution of Equation 6a. This equation has been solved exactly for some simple 1-D cases, including multilayered soils.[21,33] Numerical procedures may be used to arrive at approximate solutions to Equation 6a for more complicated cases including two-dimensional flow in multilayered soils.[33-37] The 1-D settlement of a soil layer from primary consolidation can be found by

$$S = \bar{U}H_o\Delta\bar{\sigma}_v m_v \quad (7)$$

where

$S$ = change in height, $L$

$\bar{U}$ = average degree of consolidation

$H_o$ = original depth of soil layer, $L$

The change in effective stress $\Delta\bar{\sigma}_v$ (due to an applied increment of stress $\sigma$ after dissipation of all excess pore water pressure) is equivalent to the initial magnitude of the excess pore water in the soil layer.

33. The amount and rate of consolidation of dredged material

depend on such factors as the type of soil, particle size, water content, permeability, surcharge pressure, and drainage conditions. The evaluation of the magnitude and relative contributions to the total settlement of sediment in a containment area by settling velocity processes and from primary consolidation of dredged material and underlying foundation soils is extremely complicated by various field conditions: nonhomogeneous sediment and foundation soil, magnitude and distribution of excess pore water pressures, placement rates, effect of small loading rates on consolidation behavior, lateral deformation, loss of sediment, etc. The long-term continuous disposal of a soil should cause the average degree of primary consolidation of the deposited sediments to decrease or the deposited soils to become increasingly underconsolidated with time.[38,39] The periodic disposal of dredged material in practice may not lead to significant underconsolidated sediments if adequate time is allowed between disposal operations, if the sediments are sufficiently permeable, or if sediments become desiccated from surface drying. The average degree of primary consolidation will increase after dredged material is no longer placed in the containment area.

34. The total settlement that accumulates in a gradually increasing mass of deposited sediment is assumed to occur chiefly from primary consolidation with very little secondary compression. Secondary compression is normally defined as occurring after completion of the primary consolidation. The foundation soils will also consolidate from surcharge pressure exerted by dikes surrounding the containment area and by the weight of increasing thickness of deposited sediments.

Evaluation of consolidation

35. The four approaches for evaluating the consolidation of sediments are as follows:

- a. The first approach uses an empirical equation developed by Lane and Koelzer[11] based on field data of sedimentation in streams and reservoirs.
- b. The second method is a simple application of the Terzaghi 1-D consolidation theory.
- c. The third method is an application of Gibson's[40] exact analytical solution to the progressive consolidation of a

clay layer increasing linearly in thickness with time.

*d.* The fourth approach, a new method developed to determine the consolidation of sediment increasing in thickness with time from periodic disposal of dredged material, applies a finite difference (FD) numerical technique.

The latter FD method may be applied to characterize the consolidation behavior of dredged material following the instantaneous deposition of dredged material of a given submerged unit weight at known vertical increments, while Gibson's analytical method may be applied to analyze the consolidation behavior of sediment during deposition of the sediment of a given submerged weight at a known constant rate of deposition. The result of the fourth approach should become comparable with the results of Gibson's analytical method if sufficiently small identical vertical increments are deposited at closely spaced identical intervals of time. The FD method also permits computation of consolidation of the foundation soils. Comparisons are made between these methods for consolidation on an impervious base.

36. Lane and Koelzer method. Lane and Koelzer[11] obtained field data for consolidation of sediments in streams and reservoirs that may be applicable to some dredging operations. Analysis of the field data indicated that for ponded areas where the sediment may be frequently exposed and subjected to drying by changes in the water level, the dry density as a function of time may be given for silt by

$$\gamma_d^t = 74 + 2.7 \log_{10} t \tag{8a}$$

and for clay by

$$\gamma_d^t = 46 + 10.7 \log_{10} t \tag{8b}$$

where $\gamma_d^t$ represents dry density at time $t$ yr , lb/cu ft. The dry density for sand remained fairly constant at about 93 lb/cu ft. Silt was defined as particles with diameters from 0.005 mm to 0.05 mm, while clay was defined as particles with diameters less than 0.005 mm.

37. The settlement may be found from the dry density by

$$S = H \frac{\gamma_d^t - \gamma_d^1}{\gamma_d^t} \tag{9}$$

where

$S$ = settlement, ft

$H$ = depth of sediment, ft

$\gamma_d^1$ = dry density after 1 yr, lb/cu ft

The dry densities at the end of 1 yr $\gamma_d^1$ may be estimated from the field data[11] or from Equations 8a and 8b; i.e., 74 lb/cu ft for silt and 46 lb/cu ft for clay. Large errors in settlements may result when applying field data because all sediments have been identified into only three groups, i.e., sand, silt, and clay. Variations in sediment density with depth are also not considered by this analysis.

38. Terzaghi theory. The 1-D consolidation theory is useful to obtain an estimate of the primary consolidation of a quickly deposited submerged sediment. A sediment of depth $H$ (Figure 2) is deposited and then allowed to consolidate for time $t$. Drainage is assumed to

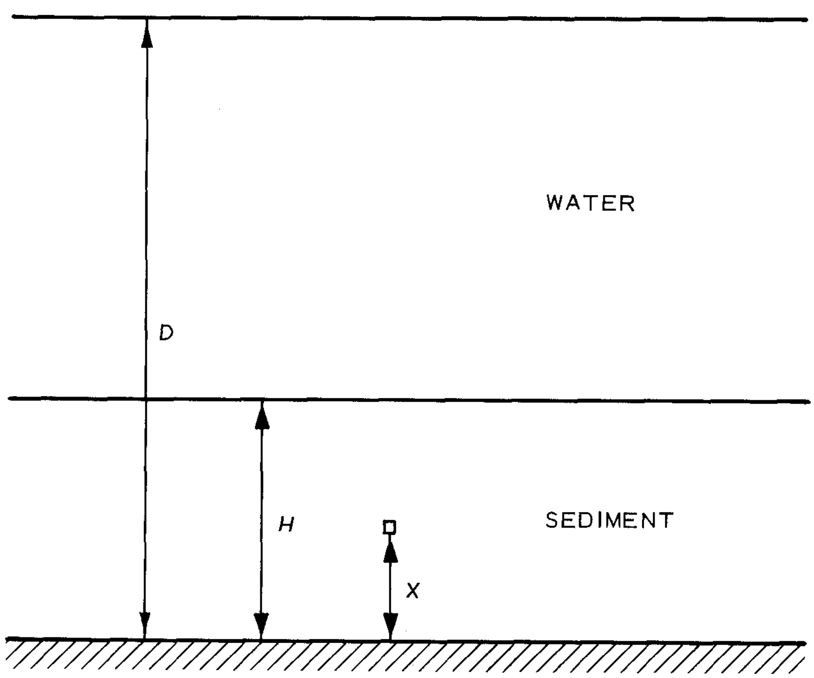



Figure 2. Consolidation on an impervious base

occur essentially from the surface of the submerged deposited sediments. A time factor is found from

$$T = \frac{c_v t}{H^2} \tag{10}$$

where

$T$ = time factor

$H$ = sediment depth and length of drainage path, L

The average degree of consolidation is found from a percent consolidation versus time factor curve,[21] and the 1-D settlement is found from Equation 7.

39. Gibson's theory. Several researchers[39,41] developed approximate solutions to the progress of consolidation in a clay layer that is increasing in thickness with time. The physical assumptions upon which these solutions are based are usually adopted from the theory of 1-D consolidation. Gibson[40] extended this work by deriving exact analytical solutions for several cases of sedimentation. The solution for progressive consolidation at a constant rate of deposition is a practical case.

40. The differential equation for consolidation at a continuous and constant rate of deposition is given by

$$c_v \frac{\partial^2 u_e}{\partial x^2} = \frac{\partial u_e}{\partial t} - \gamma_b \frac{dH}{dt} \tag{11}$$

where

$u_e$ = excess pore water pressure, $ML^{-1}T^{-2}$

$\gamma_b$ = average submerged unit weight of sediment, $ML^{-2}T^{-2}$

$H = mt$, L

$m$ = rate of deposition, $LT^{-1}$

The coefficient of consolidation $c_v$ is assumed constant.

41. Boundary conditions for an impermeable lower boundary (Figure 2) are given by

$$u_e = 0 \ , \quad x = H \tag{12a}$$

$$\frac{\partial u_e}{\partial x} = 0 \ , \quad x = 0 \tag{12b}$$

42. The solution to Equation 11 originally computed by Gibson and graphically illustrated in Figure 3 shows that the average degree of

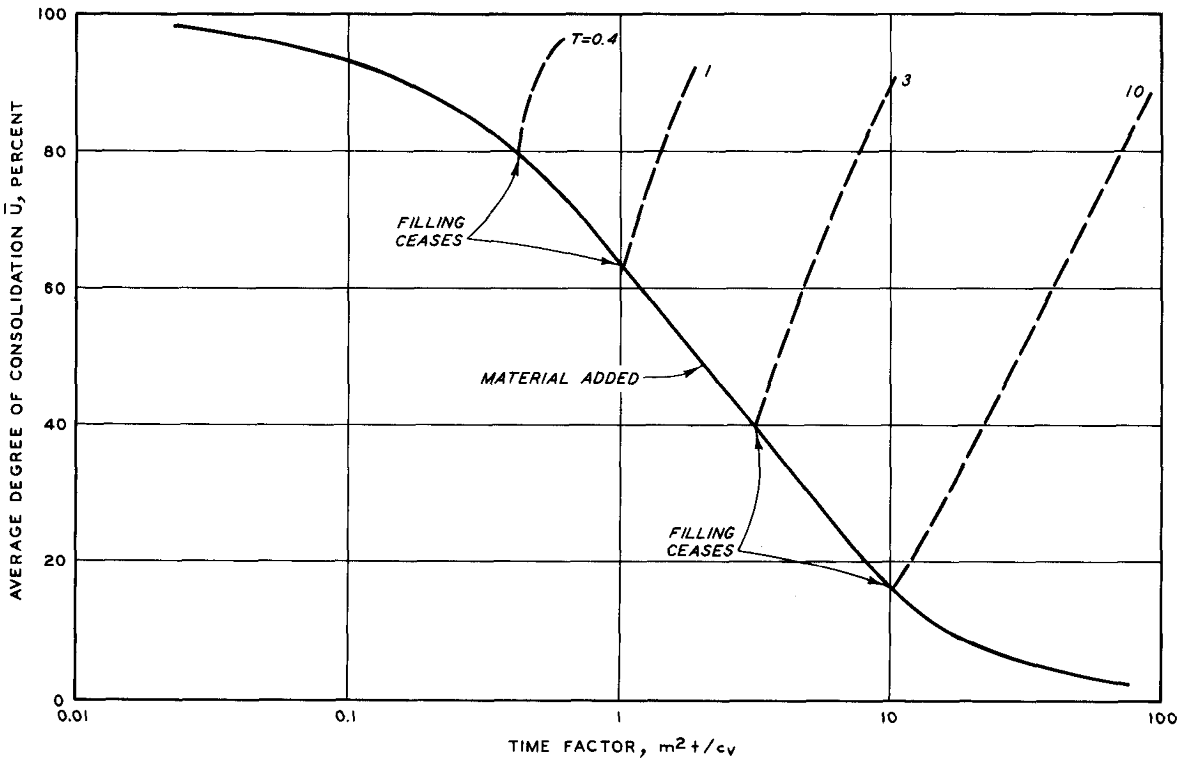



Figure 3. Relationship between the average degree of consolidation and time factor after formation of a deposit by continuous sedimentation (after Reference 40)

consolidation decreases with time for a continuous and constant rate of deposition. Sedimentation begins when time $t$, excess pore pressure $u_e$ , and height of the sediment $H$ equals zero. As sedimentation continues, the excess pore pressures build up and the average degree of consolidation $\overline{U}$ decreases. At the end of sedimentation, corresponding to some time factor

$$T = \frac{m^2 t}{c_v} \tag{13}$$

where T equals 0.4, 1, 3, or 10 (Figure 3), excess pore pressures begin to dissipate, and $\bar{U}$ will increase as shown by the dashed lines.[40] Other dissipation curves can be conveniently sketched in for appropriate time factors at which sedimentation ends. The time factor will increase linearly with depth for a constant rate of deposition (H = mt).

43. Gibson's exact analytical solution (Figure 3) may not duplicate field conditions in a containment area because the sediment must be assumed to accumulate steadily at a constant rate over the life span of the containment area. Actual conditions may approximate a rapid input of dredged slurry for a relatively short time of several weeks or months, and then the area may be left inactive and allowed to consolidate for a relatively long time. Gibson[40] has also solved the differential Equation 11 by a numerical FD procedure to permit more versatile boundary conditions and intermittent deposition of sediments. Numerical solutions to Equation 11, however, have the drawback that the technique cannot be applied initially because the sediment layer does not yet exist. The exact analytical solution may be assumed valid for initial sedimentation, and the numerical solution is then applied at a later stage. The sediment is homogeneous throughout the profile.

44. New method for determining consolidation. An FD procedure for solving the 1-D differential consolidation (Equation 6) was developed that may be more readily adaptable to actual field conditions for the disposal and consolidation of dredged material and underlying heterogeneous foundation soil. The proposed procedure permits computation of the consolidation of the dredged material and foundation soil while accounting for the effect of different soils on the dissipation of excess pore water pressures. The method provides for a drainage path that increases as the sediment layer becomes thicker, a surcharge pressure that increases from filling, and consolidation properties that may change during consolidation. The surcharge pressure in the foundation soils induced by a particular sediment thickness is assumed constant

with depth because the deposited material usually covers a large area.

45. The 1-D settlement dS from primary consolidation for a particular increment of depth dH is found by

$$dS = dH(u_{eo} - u_e)m_v \tag{14}$$

where $u_{eo}$ is initial excess pore water pressure at depth H , $ML^{-1}T^{-2}$ . The total settlement over the entire depth of the sediment is the sum of all the increments of settlement.

46. Solution of the rate of settlement from consolidation of dredged material and the underlying foundation soils requires information concerning: (a) the initial excess pore water pressure $u_{eo}$ induced by placement of the dredged sediment, and (b) the rate of dissipation of the excess pore water pressure. The distribution of excess pore water pressures in dredged material and underlying foundation soils is usually not known.

47. For this study, the excess pore water pressure in the foundation soils prior to placement of the first layer of dredged material is assumed to be zero. Placement of the first layer of dredged material is assumed to develop excess pore water pressures in both the dredged material and in the foundation soils. The excess pore water pressures are assumed to build up during bed formation to a distribution of zero at the surface of the freshly deposited bed and a maximum value at the bottom of the bed. The maximum value is not expected to exceed

$$u_{e_{max}} = \gamma_b h \tag{15}$$

where

$u_{e_{max}}$ = maximum excess pore water water pressure, $ML^{-1}T^{-2}$

h = increment of sediment depth deposited during a time interval

48. The average induced initial excess pore water pressure $u_{eo}$ in the freshly deposited sediment layer is to be represented as

$$u_{eo} = 1/2\ u_{e_{max}} \tag{16}$$

in which $u_{eo}$ is assumed to fully develop at the void ratio $e_I$ and time given by the inflection point of a sedimentation test (Figure 1). Dissipation of excess pore water pressure prior to the inflection point is considered negligible.

49. Consolidation of the sediments according to the new (proposed) method is taken to begin at the void ratio given by the inflection point of the sedimentation curve such that the initial void ratio for consolidation $e_o$ is equal to the inflection point void ratio $e_I$. The total settlement that accumulates will then be attributable to: (a) sedimentation of the initially placed dredged material until the void ratio of the sediment reaches the inflection point void ratio $e_I$ of the sedimentation curve, plus (b) settlement of the dredged sediment and foundation soils from primary consolidation.

50. The initial excess pore water pressure developed in the foundation soils from placement of the first layer of dredged material is assumed to be $u_{e_{max}}$ (Equation 15). Immediately after deposition of a subsequent layer of sediment, the excess pore water pressure in the previously placed sediments and foundation soils is increased by $\gamma_b h$. The total excess pore water pressure $u_{et}$ is now given by the sum of the $u_{e1}$ remaining before placement of the next layer plus the $u_{e2}$ arising from the additional increment of pressure $\gamma_b h$. The rate of decrease of $u_{et}$ between placement of sediment layers, which must be determined for solution of 1-D settlement, depends on the coefficient of consolidation $c_v$ and the drainage path.

51. The dissipation of the excess pore water pressure with time is found by setting Equation 6a to the special explicit FD form

$$\frac{u_{e_i}^{t+1} - u_{e_i}^{t}}{\Delta t} = c_v \frac{\left( \dfrac{u_{e_{i-1}}^{t+1} - u_{e_i}^{t+1}}{\Delta x} - \dfrac{u_{e_i}^{t} - u_{e_{i+1}}^{t}}{\Delta x} \right)}{\Delta x} \tag{17}$$

where

$u^t_{e_i}$ = excess pore water pressure at point $i$ and time $t$, $ML^{-1}T^{-2}$

$\Delta t$ = increment of time, $T$

$\Delta x$ = increment of depth, $L$

The coefficient of consolidation $c_v$ is taken as constant for a particular increment of time $t$. These FD discretizations are illustrated in Figure 4. This relatively simple FD arrangement for Equation 17

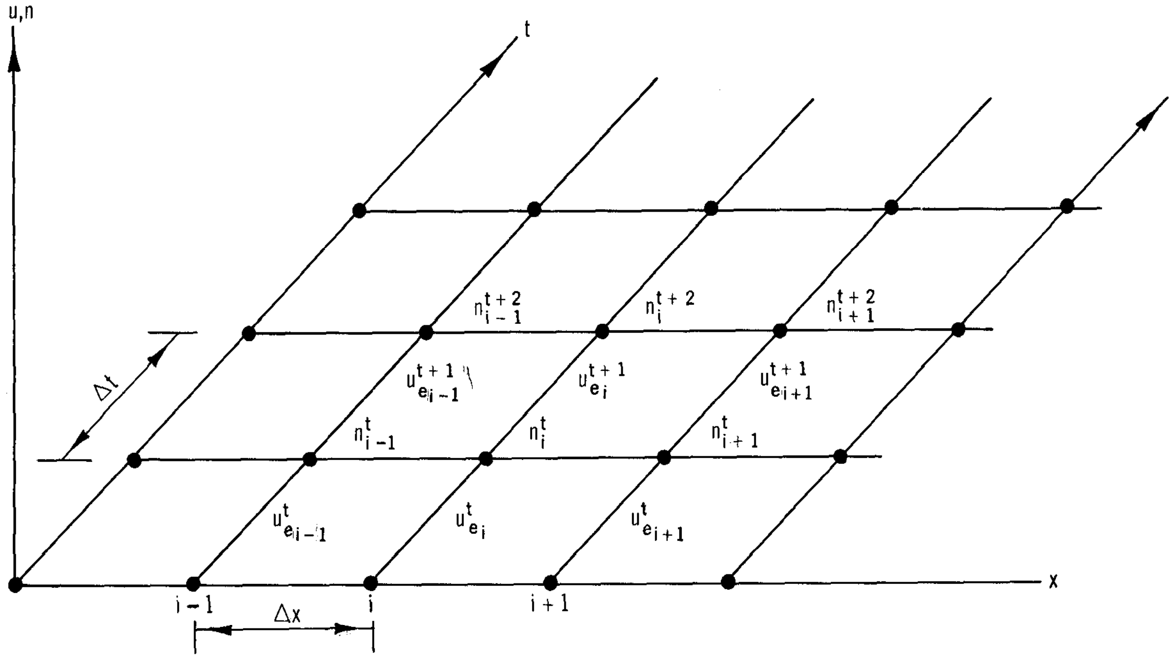
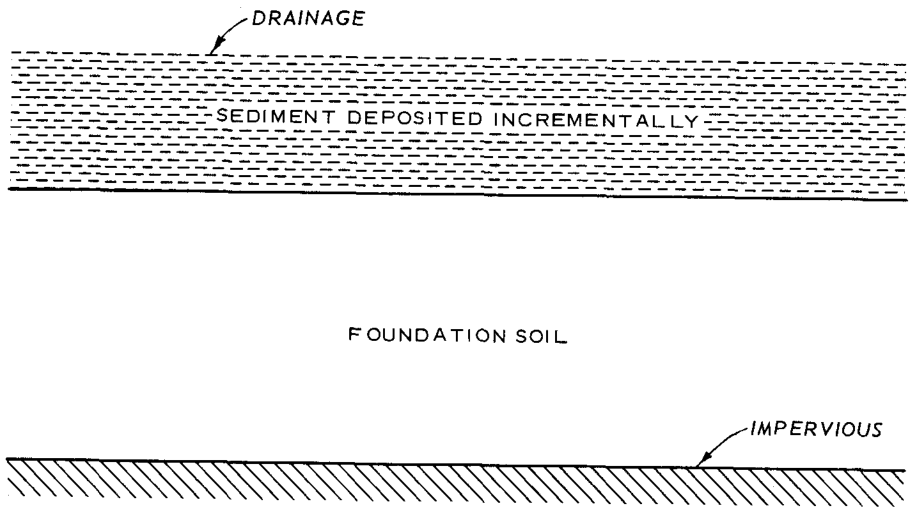


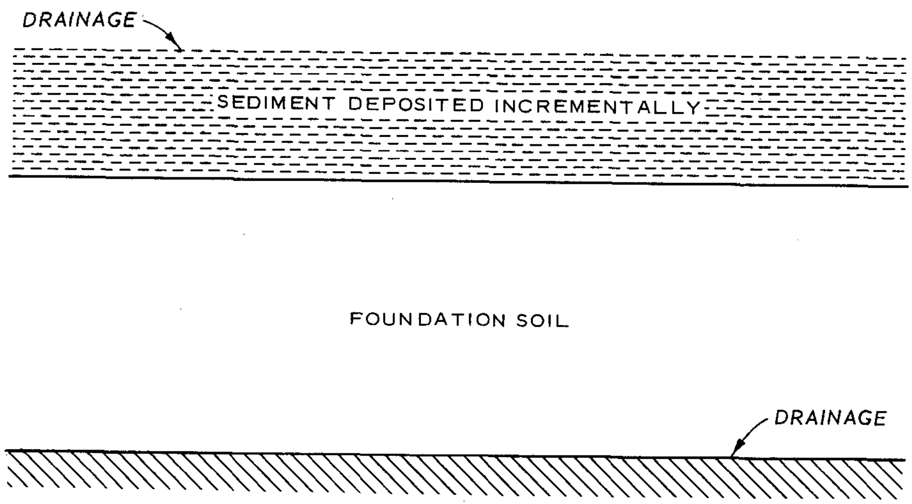

Figure 4. Finite difference mesh used in solution of Equations 17 and A14

has been shown to be sufficiently accurate and provides efficient computative effort.[42]

52. The consolidation behavior of soil will vary for different containment areas, depending on such factors as type of soil, rate and frequency of deposition, and type of drainage, and this should be evaluated for each case. For several example cases, the FD approach was applied to the determination of the average degree of consolidation $\bar{U}$ and 1-D settlements of a two-material system with (a) drainage from the surface of the sediment (surface drainage) and (b) drainage from




a. SURFACE DRAINAGE




b. DOUBLE DRAINAGE

Figure 5. Drainage conditions of two-soil systems

the surface of the sediment and bottom of the foundation soil (double drainage), as shown in Figure 5. A computer program was prepared to calculate the consolidation of a dredged clay material deposited periodically on silt or clay foundation soil (Appendix B). The computer program was designed for a heterogeneous system of foundation soil layers by introducing the condition[43]

$$\left(\frac{\partial u_e}{\partial x}\right)_m k_m = \left(\frac{\partial u_e}{\partial x}\right)_{m+1} k_{m+1} \tag{18}$$

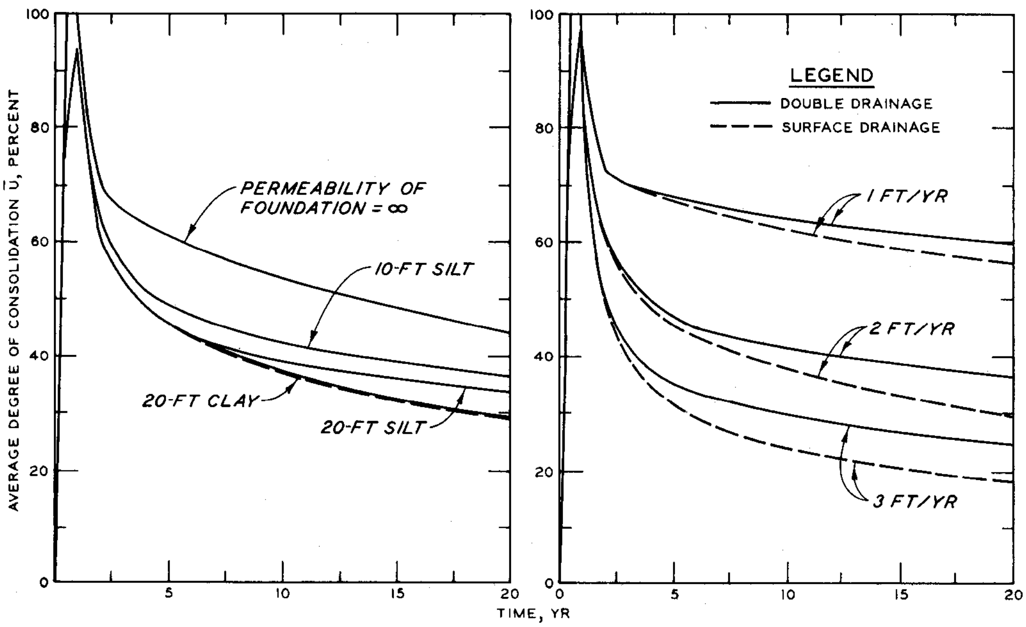
where $m$ is a layer in the soil system. The consolidation properties of the dredged material and foundation soil described in Table 4 are taken for the example cases. These properties are representative of dredged samples from the vicinity of Toledo, Ohio.[44]

53. The coefficients of consolidation, volume change, and permeability of the dredged material are reevaluated by the computer code when additional sediment layers are placed. These parameters decrease with increasing surcharge pressure exerted by the depositing sediment, while the corresponding properties of the foundation soil are assumed constant (Table 4). Solutions were found for foundation soil thicknesses of 0, 10, and 20 ft in addition to deposition rates of dredged material of 1, 2, and 3 ft/yr for surface and double drainage with silt and clay foundation soils, as described and illustrated hereinafter. A layer of dredged material (1, 2, or 3 ft thick) was deposited instantaneously, and then the dredged material and foundation soil system was allowed to consolidate for 1 yr before a subsequent layer was deposited. Each subsequent layer was deposited at 1-yr intervals. The average degree of consolidation $\bar{U}$ of the system will initially be 100 percent prior to placement of the first layer. Following placement of the first layer, $\bar{U}$ will drop to zero but will increase during the course of the year until the deposition of a subsequent layer of dredged material.

54. Foundation soil may influence the consolidation of dredged material (Figure 6a). The consolidation of the dredged sediment may not be especially affected by the foundation soil if the foundation soil overlaid an impervious stratum such that drainage can occur only in an upward direction through the surface layer of the deposited material. The consolidation of a dredged sediment deposited on a silt foundation ($c_v$ = 2 sq ft/day) with double drainage is retarded by increasing the thickness of the foundation layer. The actual consolidation and settlement calculated for the example cases are stepped (annually placed) because the layer of dredged material is assumed to

be deposited instantaneously. The data plotted in Figures 6 to 10 show smooth curves to improve clarity of the comparisons.

55. The rate of deposition of dredged material appears to greatly influence the consolidation behavior of the sediment (Figure 6b). Slower rates of sedimentation allow more dissipation of the excess pore pressures per unit time and contribute to larger calculated average degrees of consolidation.

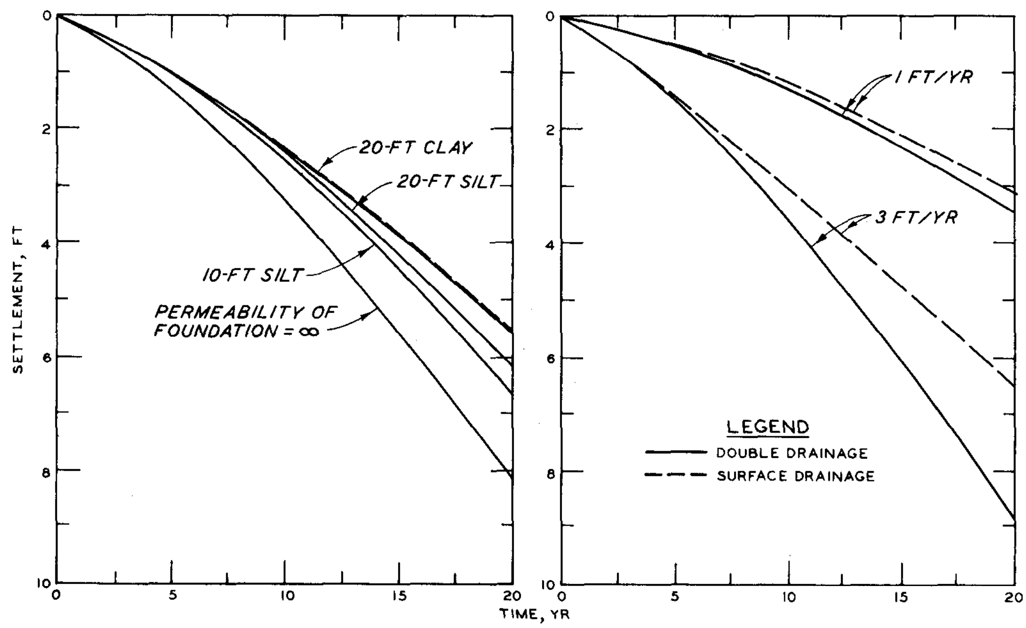



a. Two-ft/yr rate of deposition on variable foundation soil type and thickness

b. Variable deposition rate on 10-ft layer of silt foundation

Figure 6. Consolidation of dredged material on foundation soils

56. Settlements of the dredged material can be substantial (Figure 7). Thicker or less permeable foundation soil or drainage that can occur only through the surface of the dredged material (Figure 7a) may reduce the settlement. Greater deposition rates increase settlement per unit time (Figure 7b); however, the containment area will fill more quickly. Slower rates of accumulation will allow greater settlements for the same depth of dredged material. For example, after 6 yr of deposition at 3 ft/yr, the settlement is about 1.5 ft out of a total depth of 18 ft, but the settlement after 18 yr at 1-ft/yr accumulation is about 2.5 ft out of an original total depth of 18 ft.



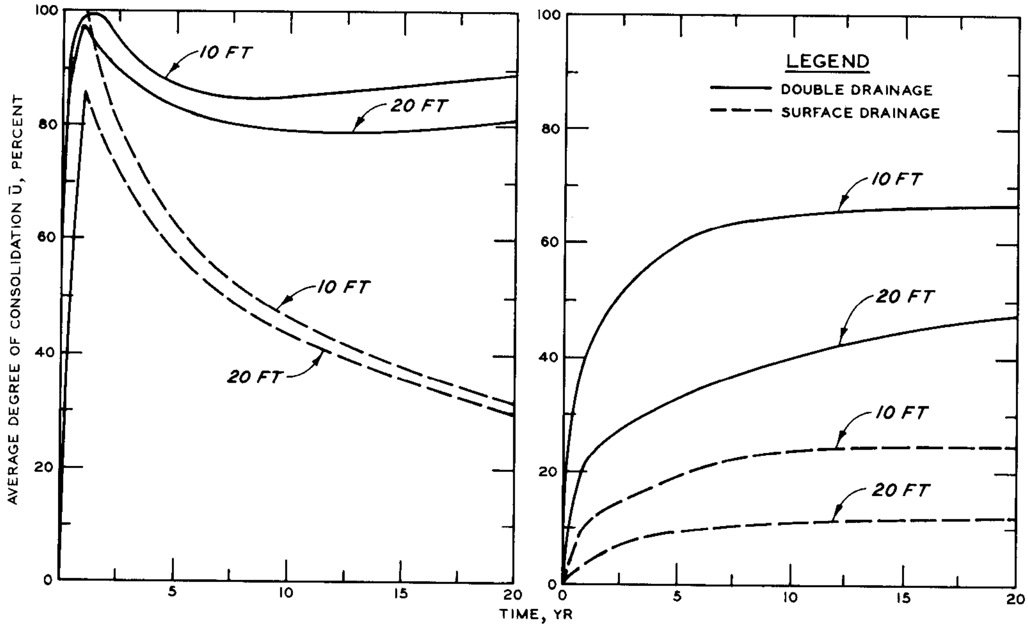

a. Two-ft/yr deposition rates and variable foundation soil thickness and type

b. Ten-ft layer of silt foundation soil and variable deposition rates

Figure 7. Settlement of dredged material on foundation soils

57. The consolidation behavior of the foundation soils may depend greatly on the type and thickness of the foundation soil and rates of deposition of dredged material (Figures 8 and 9). Double drainage was found to contribute very effectively to greater $\bar{U}$ compared with only surface drainage. Settlements for both the clay and the silt foundation soil were negligible or less than about 0.5 ft after 20 yr.

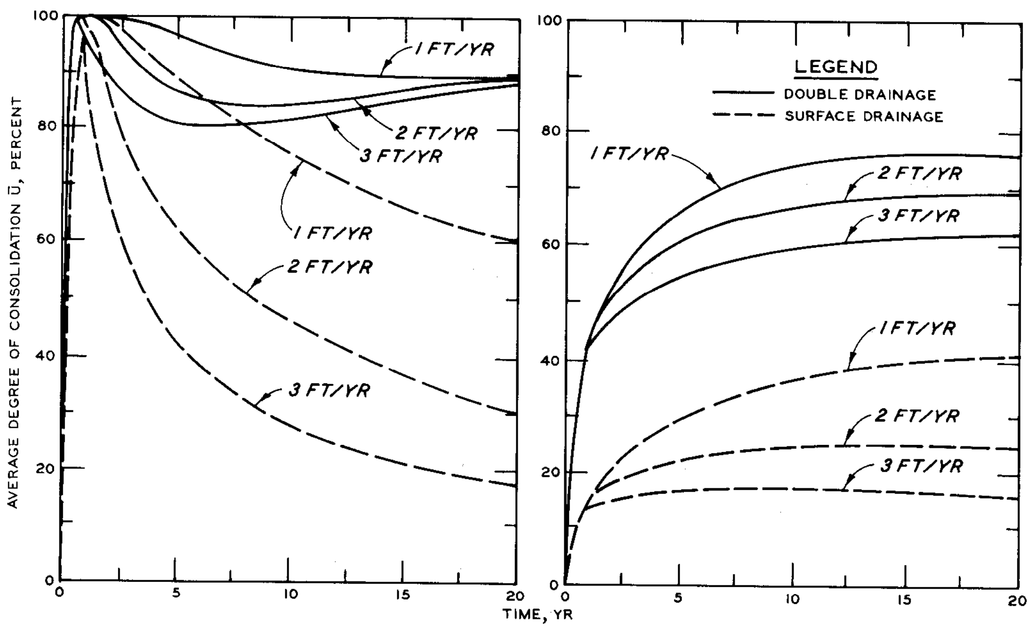
58. Lateral dissipation of excess pore water pressure in the foundation soil was not considered in any of the above 1-D analyses; however, lateral dissipation of excess pore pressures, especially in relatively permeable foundation soil, may influence the consolidation behavior of the dredged material. An approach for evaluating the relative effect of the permeability of the foundation soil on the consolidation behavior of overlying dredged material is to determine whether the foundation is essentially impervious or pervious. Bishop and Gibson[45] had shown that the consolidation of an overlying stratum is unaffected by the finite permeability of the foundation provided




a. Silt foundation ($c_v$ = 2 sq ft/day)

b. Clay foundation ($c_v$ = 0.01 sq ft/day)

Figure 8. Consolidation of foundation soils for variable thickness and a 2-ft/yr rate of deposition of dredged material




a. Silt foundation ($c_v$ = 2 sq ft/day)

b. Clay foundation ($c_v$ = 0.01 sq ft/day)

Figure 9. Consolidation of 10-ft layer of foundation soils at variable deposition rates of dredged material

$$\frac{k_F H_{DM}}{k_{DM} H_F} \geqq 10 \qquad (19)$$

where

$k_F$ = coefficient of permeability of the foundation, $LT^{-1}$

$H_{DM}$ = thickness of the dredged material, L

$k_{DM}$ = coefficient of permeability of the dredged material, $LT^{-1}$

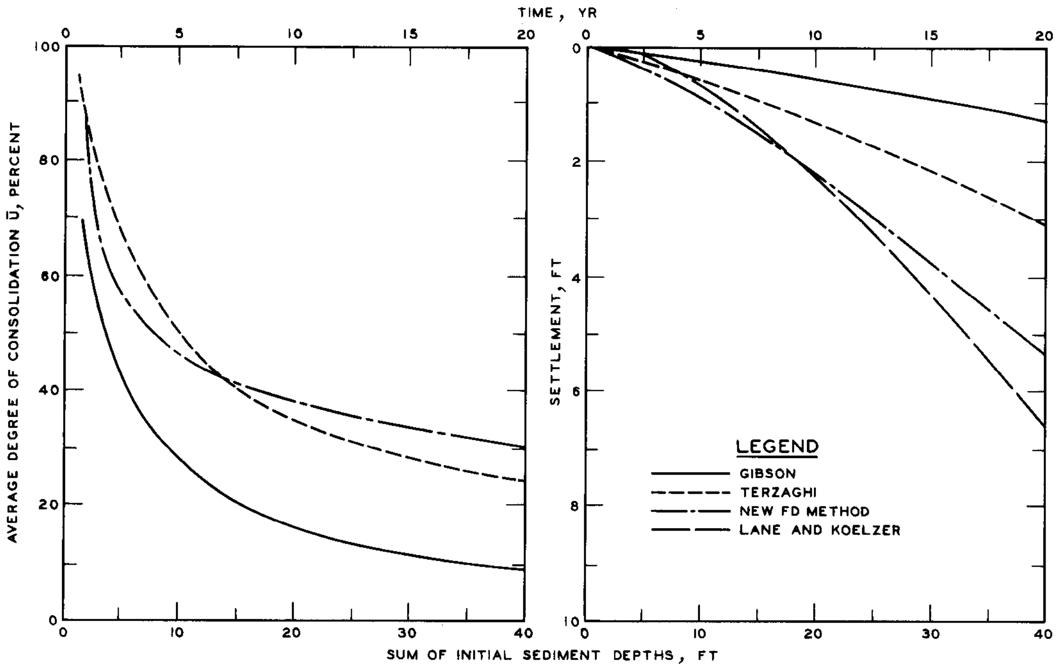
$H_F$ = thickness of the foundation soil, L

59. If Equation 19 is valid, then the foundation may be considered pervious if

| $H_{DM}/H_F$ | $k_F/k_{DM}$ |
|---|---|
| 1 | 20 |
| 2 | 10 |
| 5 | 4 |
| 10 | 2 |
| 20 | 1 |

Double drainage may be specified in the computer program of the proposed FD procedure for an essentially pervious foundation stratum or surface drainage for an impervious stratum.

60. Comparison of methods. The various methods discussed for evaluating the consolidation of clay dredged material are compared in Figure 10 for a 2-ft/yr increase of sediment depth assuming drainage from the sediment surface and an impervious foundation. The submerged unit weight $\gamma_b$ used for all materials was 28.6 lb/cu ft. Settlement by the Lane and Koelzer approach was estimated with Equations 8b and 9 for a clay sediment. Sediment layers 2 ft in depth were placed instantaneously at 1-yr intervals. Settlement from the Terzaghi 1-D consolidation theory was determined from Equation 7, and properties of the clay sediment were taken from Table 5. Pressure equivalent to $\gamma_b h$, where h equals 2 ft, was applied instantaneously at 1-yr intervals, and the coefficient of consolidation $c_v$ was assumed constant at 1.5 sq in./day. Consolidation computed by Gibson's analytical approach was estimated from solution of the time factor T (Equation 13) using the constant $c_v$ given in Table 5; the average degree of consolidation




a. Average degree of consolidation

b. Settlement

Figure 10. Comparison of the average degree of consolidation and settlement of dredged material for 2-ft/yr increase in depth computed by various methods (surface drainage)

was found from Figure 3; and the 1-D settlement was computed from Equation 7. Pressure equivalent to $\gamma_b$ mt , where m equals 2 ft/yr, was applied at a constant and continuous rate, and $c_v$ was assumed constant at 1.5 sq in./day. Settlement of the dredged material by the proposed FD method was determined using soil properties given in Table 4, which are similar to those given in Table 5. Pressure equivalent to $\gamma_b h$ , where h equals 2 ft, was applied instantaneously at 1-yr intervals and $c_v$ was variable (Table 4).

61. The 1-D settlements computed by the Lane and Koelzer approach were greater than those from the other methods, but they are only slightly more than the settlements from the proposed procedure. The computations from the Terzaghi approach predicted settlements significantly greater than those determined by Gibson's analytical solution, but smaller than those of the FD solution and the Lane and Koelzer equation.

62. The solutions from the new FD method for determining consolidation of dredged material are considered more applicable than solutions from the other methods because the data and boundary conditions introduced into the FD equations are more representative of the dredged material and field operating conditions than the assumptions used for the other methods. The FD technique suggested by Gibson[40] may also be applicable to the evaluation of the consolidation behavior of dredged material, particularly if Gibson's technique is modified to accommodate variable consolidation parameters. The above-described methods are based on the Terzaghi theory of primary consolidation, except for the Lane and Koelzer approach. If relatively low magnitudes of excess pore pressures develop in the fresh deposits of sediment, these methods may not be accurate.

63. Variation of void ratio with depth. The previously discussed methods assume a void ratio independent of depth, which may not be realistic for sediment with a large void ratio. Long[23] developed a differential equation based on consolidation theory that considers a distribution in volume ratio $\bar{E}$ with depth $x$

$$\frac{1}{\bar{E}^2}\frac{\partial \bar{E}}{\partial t} = \frac{\partial}{\partial x}\left[\frac{G}{\bar{E}^2}\left(\frac{\bar{E}}{F}\frac{\partial \bar{E}}{\partial x} - 1\right)\right] \tag{20}$$

where

$\bar{E}$ = volume ratio $(1 + e)$

$G = k(\bar{E})/\bar{K}$

$k(\bar{E})$ = coefficient of permeability as a function of $\bar{E}$, $LT^{-1}$

$\bar{K}$ = constant

$F = a_v(\bar{E})/a$, $L^{-1}$

$a_v(\bar{E})$ = coefficient of compressibility as a function of $\bar{E}$, $M^{-1}LT^2$

$a$ = constant, $M^{-1}L^2T^2$

64. The influence of excess pore pressure is considered in Equation 20 by insertion of a limiting boundary condition, which is the void ratio when the excess pore pressure is zero. Void ratios corresponding to zero excess pore pressure may be evaluated from given

effective pressures of consolidation test results. Equation 20 is not used in the computer code (Appendix B) to determine consolidation.

65. <u>Nonflooded conditions.</u> In all the methods presented, the containment area is assumed to be flooded. If the containment area is not flooded and the material is no longer saturated, consolidation may increase due to higher effective stresses in the soil mass. The top layer of sediment will probably also become desiccated. The desiccation will increase the rate of consolidation of the sediments; however, a crust may form over the sediment surface that may retard evaporation of pore water from the deeper soil layers.[46] None of these conditions may be accounted for by the previously presented theories.

## PART III: APPLICATIONS

### Procedure for Sizing Containment Areas

66. The following procedure for sizing containment areas is presented primarily to demonstrate the application of the methodology developed during this study to estimate the time-rate of change in capacity of a containment area. Many of the simplifying assumptions made throughout the presentation are recognized to be major considerations in the design process and are the subject of research currently being conducted as part of the DMRP. Steps of a tentative procedure for sizing containment areas are listed below:

- a. Step 1: Determine permissible solids and percent of solids by weight in the discharge effluent.
- b. Step 2: Determine water content or in situ dry density and total volume of material to be dredged, including overdredging.
- c. Step 3: Estimate the reduction in volume with time of the dredged material from sedimentation and deposition on the bed of the containment area.
- d. Step 4: Estimate the reduction in volume with time of the dredged material and foundation soils from consolidation following sedimentation.
- e. Step 5: Check the calculated containment area volume required to accommodate a given volume of in situ material to be dredged by reference to local experience if available.

67. The permissible solids and percent of solids by weight permitted in the discharge effluent (step 1) are usually predetermined by local water-quality standards. The containment area and disposal operation may be designed to provide discharge water of the proper quality. Development of practical procedures for the proper design of containment areas is difficult because of many factors and field conditions that may affect the effluent quality. Procedures are being developed as part of the DMRP.

68. The in situ water content or dry density and total volume of material to be dredged (step 2) may be determined by local experience,

sampling of the in situ sediment, and survey of the depth of the material to be dredged. The fraction of solids $F_i$ input into the containment area may be estimated by reference to past experience, a field test of a small-scale or pilot dredging operation, or perhaps by production rates of the dredge.

69. Estimates of the reduction in volume with time from sedimentation of the dredged material (step 3) and from consolidation of the dredged material and foundation soils (step 4) are complicated by many factors that include the manner of operating the disposal of dredged material, the type of sediment, and the carrying water. Only a few of the many possible situations can be illustrated here. A decision may be made, for example, to place the entire dredged material in a relatively short time before any water is to be discharged from the containment area; i.e., the dredged material may be placed in a holding area within the containment area such as may be necessary for some dispersive types of clay slurries. The initial absolute maximum required capacity in the containment area may then be estimated from volume and weight relationships by

$$V_{ca} = B_o V_{in} \tag{21}$$

where

$$B_o = \frac{100G_s}{F_i(100 + w_{in}G_s)} \left(100 + \frac{F_i}{G_s} - F_i\right)$$

The parameter $B_o$ is applied prior to any sedimentation of the clay slurry input into the containment area or discharge of any water from the area. The initial void ratio of the clay slurry can be given by

$$e_{os} = G_s\left(\frac{100}{F_i} - 1\right) \tag{22}$$

The initial void ratio is needed for determination of the settlement from sedimentation processes.

70. In case the volume of slurry to be input into the containment area $V_{in}$ exceeds the actual capacity of the containment area $V_{ic}$, then dredging may be stopped, alternate containment areas may be used, or in the most common cases, ponded water may be discharged over a weir if the effluent quality of the water is satisfactory. The actual capacity or volume available in an existing containment area may be determined from an analysis of a level survey of the area.

71. For a decision to discharge ponded water over a weir, the dredging operation may be performed in a manner to input the material at a rate to permit continuous operation, but to also allow discharge of ponded water of the necessary efficiency (Equation 2) or within acceptable levels of suspended solids. Evaluation of the discharge rate from the containment area $Q_d$ may be difficult because a satisfactory discharge rate depends on many conditions such as retention of solids in the containment area (efficiency), type of sediment, seepage through the dike and through underlying foundation soils, number and configuration of discharge weirs, and installation of special features such as filters. If the allowable discharge rate to meet suspended solids standards is too small, the input rate $Q_{in}$ may be reduced to a level that does not permit efficient operation of the dredges, and additional containment areas may be required to place the dredged material.

72. An estimate of the reduction in volume of the dredged material with time from sedimentation (step 3) may be made from Equation 4 until sedimentation is essentially complete as indicated by an abrupt decrease in void ratio with time (inflection point, Figure 1). A slurry sedimentation test may be necessary to evaluate the $\alpha_o$ and $\tau$ parameters (Equation 4) and the inflection point void ratio (Figure 1). The inflection point void ratio $e_I$ is taken as the initial void ratio $e_o$ for consolidation, and it is assumed to be fairly constant for a particular sediment. The sedimentation test may be performed in a cylinder of a fairly large diameter (6 or more in.) to minimize drag on the suspended particles from the surface of the cylinder. The depth

of dredged material in the cylinder should be comparable to the depth of dredged material placed during a single disposal operation in the containment area. The fraction of solids and the chemical content of the water should be comparable to the fraction of solids $F_i$ and the chemical content of the water input into the containment area. A slurry consolidation test may be necessary to determine the consolidation parameters for solution of settlement by the computer program (Appendix B). The thickness of the sediment layer H for calculation of settlement from primary consolidation is determined from Equation 5 where e is the inflection point void ratio $e_I$, and $e_{os}$ is the initial void ratio in the containment area prior to sedimentation (Equation 22).

73. The reduction in volume or settlement from primary consolidation of the dredged material and foundation soils (step 4) may be estimated by the computer code (Appendix B). The time required for consolidation is usually significantly more than the time required for sedimentation. The amount of additional settlement by consolidation for sand and some silt materials may be sufficiently small such that any settlement from consolidation following sedimentation may be ignored. The consolidation of most clay sediments may be significant in time and should be added to the settlements calculated by the sedimentation process (Equation 4).

74. The estimate of the reduction in volume of the dredged sediment from sedimentation and consolidation of the dredged material and foundation soil should be checked by reference to local experience if available (step 5). The above tentative procedure is unproven and must be confirmed or modified as necessary by comparisons with practical field experience.

## Example

### Input data

75. In order to demonstrate the determination of size requirements for a containment area, the following variables and parameters

were selected to represent a dredged material comprised of clay:

| | |
|---|---|
| Efficiency $E$ | 85 percent |
| In situ water content $w_{in}$ | 200 percent |
| Total volume to be dredged $V_{in}$ | $1.0 \times 10^6$ cu yd |
| Input rate at in situ water content $Q_{in\ situ}$ | 50,000 cu yd/day |
| Average particle diameter $d_{50}$ | 0.0014 mm |
| Specific gravity of solids $G_s$ | 2.65 |
| Fraction of solids in slurry $F_i$ | 15 percent by weight |
| Initial capacity of containment area $V_{ic}$ | $5.0 \times 10^6$ cu yd |
| Area of containment area $A_{ca}$ | $1.17 \times 10^6$ sq yd (900 by 1300 yd) |

76. The results of a sedimentation test indicated a sedimentation curve given by the experimental curve in Figure 1. The $\alpha_o$ parameter was $10.7 \times 10^{-6}$ and the $\tau$ parameter was 0.6 as determined from the sedimentation test results. The results of a slurry consolidation test of the dredged material indicated consolidation parameters given in Table 4.

77. The containment area is new with dikes 15 ft in height permitting a maximum depth of 13 ft of dredged material and ponded water in the containment area, if 2 ft is allowed for freeboard. The foundation soils are composed of 20 ft of clay underlain by 20 ft of silt with consolidation parameters given in Table 4. The bottom of the silt is assumed to rest on a pervious sand stratum (Figure 11). The foundation profile containing several types of soil was chosen to demonstrate the capability of the computer code to calculate the consolidation behavior of a heterogeneous foundation system. The sand is pervious with respect to the silt, and the silt is pervious with respect to the clay foundation (Figure 11). The original elevation of the ground surface is taken as zero. One dredging operation described by the above

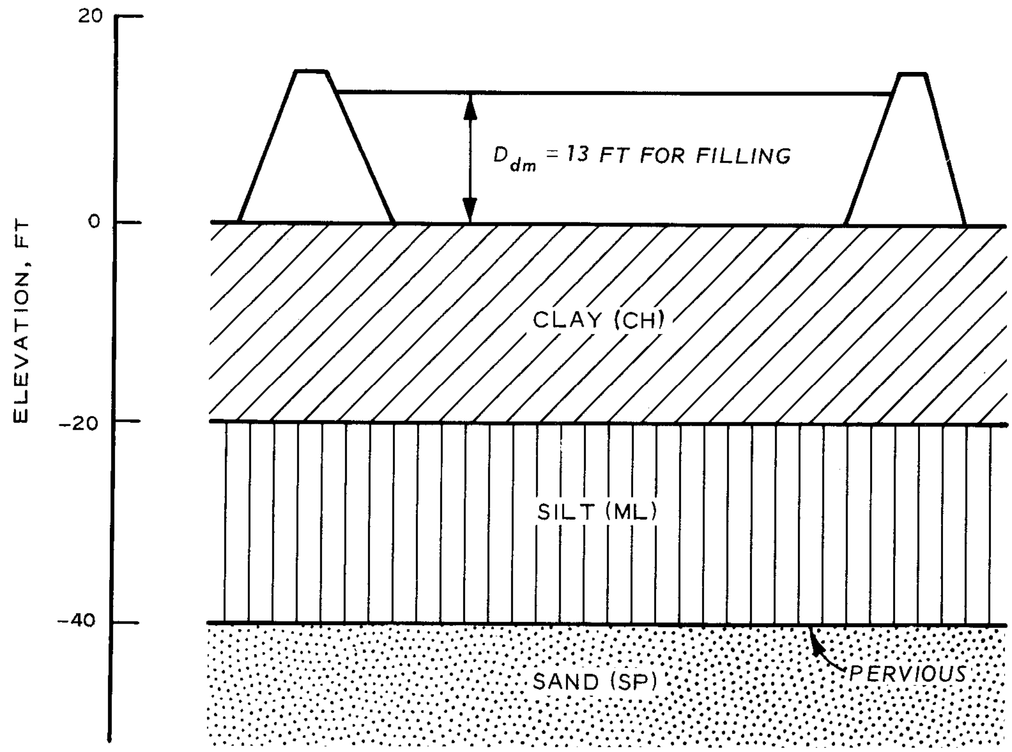



Figure 11. Example containment area

variables is assumed to occur annually until the containment area is filled to capacity. The dikes will be raised an additional 4 ft to increase capacity after a certain number of dredging operations (exact number to be determined). The rate at which the containment area is filling with dredged material and the probable time at which the area reaches its capacity are to be estimated.

Starting conditions

78. The parameter $B_o$ is computed as given with Equation 21.

$$B_o = \frac{(100)(2.65)}{(15)[100 + 200(2.65)]} \left(100 + \frac{15}{2.65} - 15\right) = 2.54$$

Then, if effluent is not discharged, the initial required capacity in the containment area (Equation 21) is calculated to be

$$V_{ca} = B_o V_{in} = 2.54 \ (1.0 \times 10^6) = 2.54 \times 10^6 \text{ cu yd}$$

79. The input rate into the containment area will become

$$Q_{in} = B_o Q_{in\ situ} = 2.54\ (50{,}000) = 127{,}000 \text{ cu yd/day} \qquad (23)$$

The dredged material will be input into the containment area, assuming a round-the-clock dredging operation, for a period of

$$t_{do} = \frac{V_{ca}}{Q_{in}} = \frac{2.54 \times 10^6}{0.127 \times 10^6} = 20 \text{ days} \qquad (24)$$

where $t_{do}$ is the time required for a single dredging operation.

80. The initial void ratio of dredged material entering the containment area will be (Equation 22)

$$e_{os} = 2.65\left(\frac{100}{15} - 1\right) = 15.0$$

81. If water is not discharged from the containment area during the disposal operation, the depth of dredged material in the containment area may reach up to

$$D = \frac{V_{ca}}{A_{ca}} = \frac{2.54 \times 10^6}{1.17 \times 10^6} \times 3\ \frac{\text{ft}}{\text{yd}} = 6.5 \text{ ft} \qquad (25)$$

Reduction in
volume from sedimentation

82. The depth of dredged material after sedimentation (Equation 5) is then estimated as

$$H = \frac{D(1 + e)}{1 + e_{os}} = \frac{6.5(1 + 4)}{1 + 15} = 2.0 \text{ ft}$$

The void ratio $e$ is the inflection point void ratio $e_I$ (Figure 1), which is estimated from the laboratory sedimentation test.

83. The time for sedimentation may be estimated from Equation 4 in the following manner. For an $\alpha$ parameter of

$$\alpha = \frac{\alpha_o D}{d_{50}^{2.15}} = \frac{10.7 \times 10^{-6} D}{(0.0014)^{2.15}} = (14.63)(6.5) = 95.1 \text{ days}$$

The time required to settle the dredged material from an initial depth $D$ of 6.5 to 2.0 ft is

$$t_{6.5} = \left(\frac{\alpha}{e} - \frac{\alpha}{e_o}\right)^{1/\tau} = \left(\frac{95.1}{4} - \frac{95.1}{15}\right)^{1/0.6} = 117.2 \text{ days}$$

Additional research will be necessary to determine the most appropriate diameter (d) of particles; i.e., whether $d_{10}$, $d_{50}$, or $d_{90}$ is more applicable for sediments containing a range of particle sizes. The time required for sedimentation may be excessive and, as often done, may be reduced by discharging ponded water.

84. A practical solution to the discharge rate $Q_d$ is beyond the scope of this study. For this example problem, it is assumed that a 4-ft depth of dredged material was found adequate to discharge effluent water of permissible quality. The volume $V'_{ic}$ of needed capacity for a single disposal operation will then be

$$V'_{ic} = A_{ca} D = (1.17 \times 10^6)(4)(0.33 \text{ yd/ft}) = 1.56 \times 10^6 \text{ cu yd} \tag{26}$$

The volume of water to be discharged is

$$V_d = V_{ca} - V'_{ic} = (2.54 - 1.56) \times 10^6 = 0.98 \times 10^6 \text{ cu yd} \tag{27}$$

The initial capacity $V_{ca}$, if effluent water is not discharged, was found from Equation 21 and paragraph 78.

85. The time taken to fill the containment area to a depth of 4 ft during one dredging operation will be

$$t_4 = \frac{V'_{ic}}{Q_{in}} = \frac{1.56 \times 10^6}{0.127 \times 10^6} = 12.3 \text{ days} \tag{28}$$

Ponded water is assumed for this example problem to be discharged at a rate equal to the input rate $Q_{in}$ of 127,000 cu yd/day for the remaining

$$t_d = t_{do} - t_4 = 20 - 12.3 = 7.7 \text{ days} \tag{29}$$

where $t_d$ is the time required for discharge of ponded water. The discharge water is assumed to carry a fraction of solids by weight of (Equation 2)

$$F_o = F_i - \frac{EF_i}{100} = 15 - \frac{(85)(15)}{100} = 2.25 \text{ percent}$$

which is the maximum percent of permissible solids in the discharge effluent.

86. The weight of solids remaining in the containment area $W'_{sca}$, following the discharge of the effluent water at the end of a disposal operation (after 20 days), is

$$W'_{sca} = W_{sca} - W_{sd} = (710 - 70) \times 10^6 = 640 \times 10^6 \text{ lb} \tag{30}$$

where

$W_{sca}$ = initial weight of solids in the containment area, $MLT^{-2}$

$$= \frac{V_{in} G_s \gamma_w}{(100 + w_{in} G_s)} \times 100 = \frac{(10^6)(2.65)(62.5)(100)}{100 + 200(2.65)} \times 27 \frac{\text{cu ft}}{\text{cu yd}}$$

$$= 710 \times 10^6 \text{ lb}$$

$W_{sd}$ = weight of solids discharged from the containment area, $MLT^{-2}$

$$= \frac{F_o \gamma_w V_d}{100 - F_o + \frac{F_o}{G_s}} = \frac{(2.25)(62.5)(1.82 \times 10^6)}{100 - 2.25 + \frac{2.25}{2.65}} \times 27 \frac{\text{cu ft}}{\text{cu yd}}$$

$$= 70 \times 10^6 \text{ lb}$$

The fraction of solids $F'_i$ remaining in the containment area following discharge of the effluent water will be

$$F'_i = \frac{100W'_{sca}}{W'_{sca} + \gamma_w\left(V'_{ic} - \frac{W'_{sca}}{G_s\gamma_w}\right)} \tag{31}$$

$$= \frac{(100)(640 \times 10^6)}{640 \times 10^6 + 62.5\left[(1.56 \times 10^6)\left(27 \frac{\text{cu ft}}{\text{cu yd}}\right) - \frac{640 \times 10^6}{(2.65)(62.5)}\right]}$$

$= 21.1$ percent

87. The initial void ratio following discharge of the effluent 20 days after the start of the operation (termination of the disposal operation) is

$$e'_{os} = G_s\left(\frac{100}{F'_i} - 1\right) = 2.65\left(\frac{100}{21.1} - 1\right) = 9.91 \tag{32}$$

The sediments following termination of the disposal operation will settle from the void ratio $e'_{os}$ of 9.91 until the inflection point void ratio of 4.0 is attained.

88. The additional time required to settle these sediments from $e'_{os}$ will be based on an $\alpha$ parameter from Equation 4

$$\alpha = \frac{\alpha_o D}{d_{50}^{2.15}} = (14.63)(4) = 58.5 \text{ days}$$

By substitution, the time required to reach the inflection point void ratio after the termination of a single dredging operation will become

$$t' = \left(\frac{\alpha}{e} - \frac{\alpha}{e_{os}}\right)^{1/\tau} = \left(\frac{58.5}{4} - \frac{58.5}{9.91}\right)^{1/0.6} = 37 \text{ days} \tag{33}$$

Then, the total time for the disposal operation and sedimentation may be expressed as

$$t_t = t_{do} + t' = 20 + 37 = 57 \text{ days} \tag{34}$$

89. The depth of the dredged material (Equation 5) following sedimentation at 57 days will be

$$H = \frac{D(1 + e)}{1 + e'_{os}} = \frac{4(1 + 4)}{1 + 9.91} = 1.8 \text{ ft}$$

90. Dredging operations if done annually will continue until the depth of the dredged material and ponded water $D_{dm}$ reaches about 13 ft. The number of annual operations $N$ may be calculated as follows:

$$N = \frac{D_{dm} + H - D}{H} = \frac{13 + 1.8 - 4}{1.8} = 6 \tag{35}$$

After about six annual operations, the accumulated depth $H_d$ will be approximately

$$H_d = NH = (6)(1.8) = 10.8 \text{ ft} \tag{36}$$

The remaining 2.2 ft (13 - 10.8) of space is reserved for ponding water. The dikes may be raised after about 5 yr or six dredging operations to allow additional placement of dredged material.

## Reduction in volume from consolidation

91. The computer program (Appendix B) may be used to determine additional settlement from consolidation of the dredged material and foundation soils. The calculations could be done fairly easily by hand for relatively few dredging operations and for a homogeneous soil system with constant consolidation parameters by applying existing consolidation theory. The code, however, can save considerable time when numerous dredging operations and heterogeneous soil are involved.

92. The dredged material for each operation is assumed to be deposited in three increments of 0.6 ft/increment at 20-day intervals. The dredged material and foundation soils (Figure 11) are assumed to consolidate for the remaining 304 days of the year before placement of additional dredged material. The code was programmed to perform nine

dredging operations spaced at annual intervals. The first dredging operation began at year zero. Consolidation of the dredged material and foundation soils was computed for an additional 3 yr after termination of all dredging operations.

93. The average degrees of consolidation $\overline{U}$ of the dredged material and foundation soils are illustrated in Figure 12. The $\overline{U}$ of

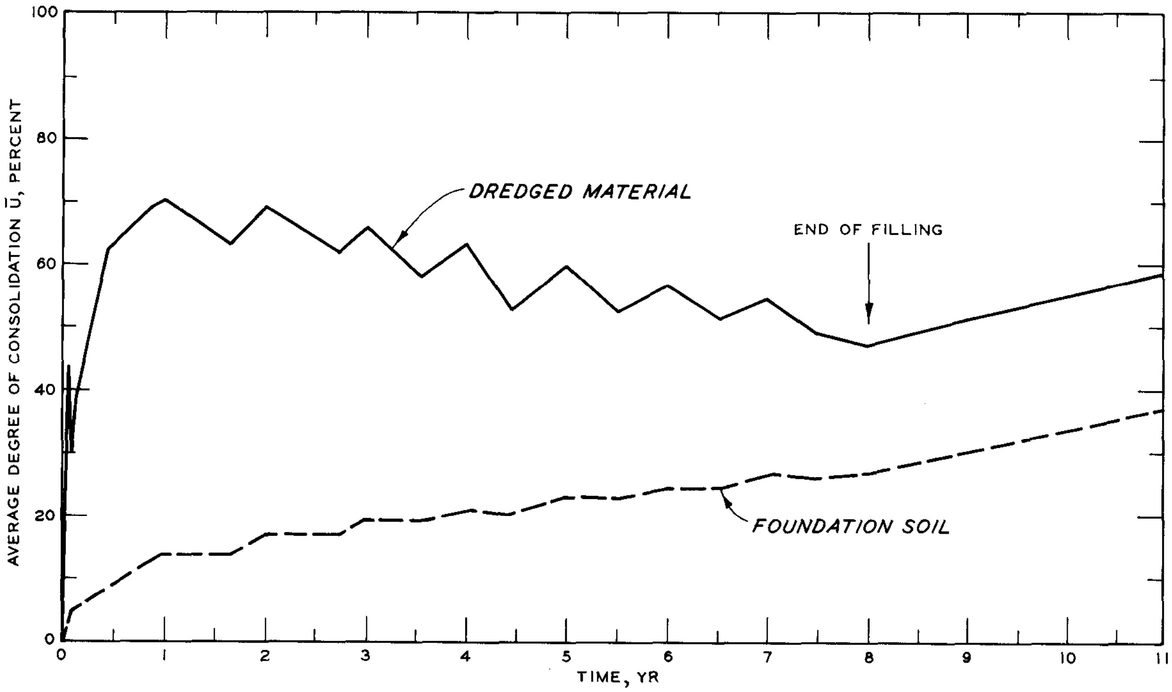



Figure 12. Average degree of consolidation of the dredged material and foundation soil with time

the dredged material is maximum at one year following the second disposal operation and tends to decrease with time thereafter until the end of filling or termination of all disposal operations. The $\overline{U}$ of the dredged material subsequently increases with time after filling is complete. The sawtooth behavior of the consolidation curve is due to the placement of dredged material. The $\overline{U}$ of the foundation soils (20 ft of clay overlying 20 ft of silt) is less than that of the dredged material at each time level and tends to increase with time.

94. Settlement from consolidation of the dredged material (Figure 13) is significant and contributes about 1.25 ft of additional depth

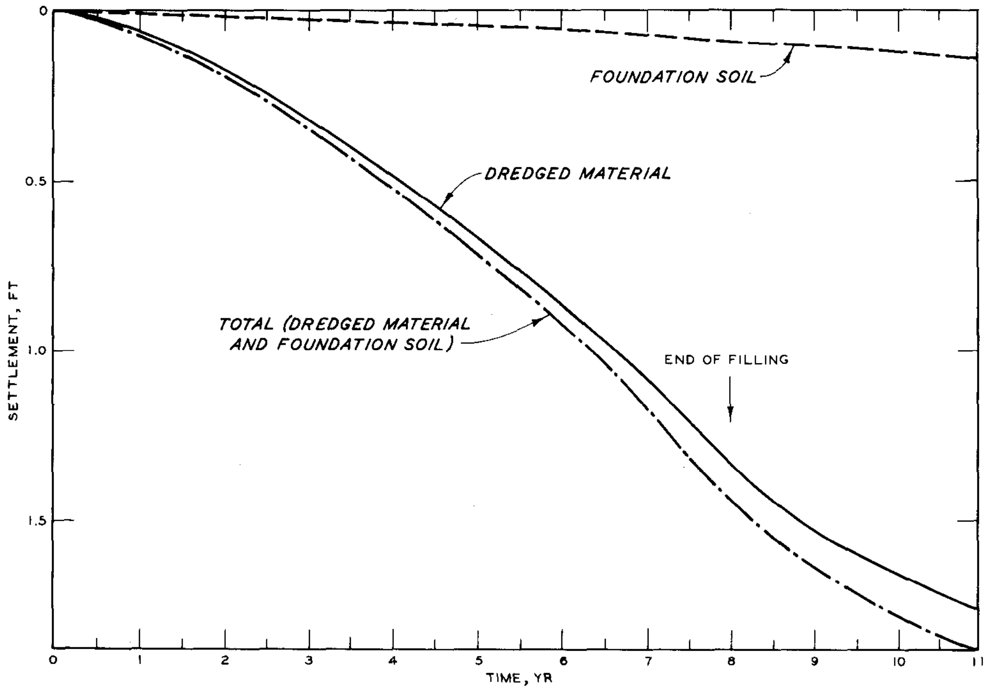



Figure 13. Settlement with time of the dredged material and foundation soil

available for placement of dredged material after 8 to 9 yr. Likewise, settlement from consolidation of the foundation soils contributes an additional 0.25 ft for a total settlement of about 1.5 ft for the same period of time. It should be noted that the dikes may also settle due to consolidation of the underlying soils. This settlement is not considered in the analysis. The dikes could be constructed to minimize settlement or could be periodically raised to compensate for the settlement.

95. Raising the height of the dikes by 4 ft will increase the total height to 19 ft, thus permitting 17 ft for placement of dredged material. The total height of dredged material after nine disposal operations is 16.2 ft less 1.5 ft from consolidation to give 14.7 ft. The available space for ponded water during the last disposal operation is 17.0 - 14.7 or 2.3 ft, which is adequate assuming that 4 ft of dredged material and ponded water for each disposal operation will lead to satisfactory levels of suspended solids in the discharge effluent.

# PART IV: CONCLUSIONS AND RECOMMENDATIONS

## Conclusions

96. Bulking and design factors have been developed for dredged material in some regions of the United States, usually on the basis of local experience. These factors provide information on the ultimate densities of dredged material or on densities that might be expected after most sedimentation and consolidation have been completed. The classification of bulking factors is not well developed according to soil properties such as the type of soil, grain-size distribution, and chemical content of the pore water.

97. Estimates of the volume made available by the reduction in water content with time of dredged material can be made by consideration of settling velocity phenomena during sedimentation and by primary consolidation theory during consolidation. The time of transition from sedimentation to consolidation and the consolidation of the freshly deposited sediments depend strongly on the development and dissipation of excess pore water pressures in the dredged material. The method of determining sedimentation suggested in Part II together with empirical observations can be exploited further to give additional information relating to the time required for various types of materials to settle or drop out of suspension in the disposal area as required to achieve proper effluent quality.

98. The Terzaghi theory of 1-D primary consolidation may be applied to calculate the settlement of dredged material and foundation soils following the volume reduction predicted by settling velocity theory. The FD method developed during this study for determining consolidation is designed specifically for computation of the consolidation and settlement of dredged material and foundation soils in confined disposal areas. Application of consolidation theory to cases where the effective stresses may be small, such as stresses that may occur from placement of thin layers of sediment, may be in doubt,

however, and should be evaluated further by analyses of field and laboratory sedimentation and consolidation tests.

## Recommendations

99. The subject of settling and sedimentation behavior of suspensions of dredged material should be pursued further to include experimental and additional theoretical studies. Sedimentation and consolidation tests should be performed in the laboratory and compared with the predictions made by the new method proposed for evaluating sedimentation behavior. The new method should be made more flexible to include an allowance for input and discharge rates into and out of the containment area. The sizing, layout, and operation of containment areas necessary to meet suspended solids requirements should be analyzed using the new method of determining sedimentation together with other methods and empirical observations of the time required for various types of materials to settle in disposal areas.

100. The mechanism of the transition from sedimentation to consolidation should be investigated in greater detail. This investigation should include measurements of excess pore water pressure with time. Efforts should be made to relate densities at the completion of sedimentation with Atterberg limits data, especially at the upper liquid limit. A representative range of material should be tested including actual samples of dredged material (i.e., silty sands, nonplastic silts, plastic silts, and clay of various plasticity indexes), so that detailed testing for a specific location may not be necessary.

101. Consolidation characteristics of freshly sedimented materials under exceedingly small loads should be experimentally determined for a representative range of materials and results compared with available theories. Special consolidometers should be designed to accommodate sedimentation and subsequent loading under exceedingly small loads.

102. The 1-D FD procedure proposed for evaluating the consolidation of dredged material and foundation soils in flooded containment areas should be expanded to include two-dimensional consolidation to

allow for lateral dissipation of excess pore water pressures. Settlements computed by numerical procedures should be investigated further to establish relationships between settlements, placement rates of dredged material, thickness of foundation soils, grain size of the soils, Atterberg limits, etc., as aids to simplifying the sizing problems of containment areas.

103. Containment area operations and the field behavior of dredged sediment should be closely monitored to obtain data to check various theoretical formulations such as those that predict the settlement of dredged material and foundation soils. These data should include records of the fraction of solids of slurry input to the containment area, rate of input, particle-size distribution and plasticity, ponding depth, rate of discharge of ponded water, fraction of solids in the water discharged from the containment area, total volume input, currents, and changes in sediment density with time.

104. Field explorations of existing sites to determine details of stratification, density, particle-size distribution, and pore water pressures with depth would also be useful. Benchmarks should be placed in the sediment and foundation soils to determine changes in elevation and thus to monitor settlements. Piezometers should also be installed to monitor the rate of increase and decrease of excess pore water pressures. Occasional undisturbed boring samples may be taken from the containment area sediment and foundation soils for analysis of the consolidation properties and the change in dry density and water content as a function of time. Access tubes could be installed for water content and density measurement by nuclear methods.

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Table 1

Summary of Quantities of Dredged Material

Based on Grain Size*

| Group | Classification | Annual Quantity, $10^6$ cu yd |
|---|---|---|
| A | Mud, clay, silt, topsoil, shale | 80.2 |
| B | Silt and sand mixed | 153.2 |
| C | Sand, gravel, shell | 52.4 |
| D | Organic muck, sludge, peat, muncipal-industrial waste | 1.4 |
| E | Mixed | 11.2 |
| | Total | 298.4 |

* Figure 3, Reference 1.

Table 2

Bulking and Design Factors According to Region

| Region | Percent Sediment by Group A | B | C | D | E | Bulking or Design Factor | Reference |
|---|---|---|---|---|---|---|---|
| Chicago | 10 | 25 | 15 | 50 | | 2.0 | 3 |
| Galveston | 15 | 80 | 5 | | | 1.5* | 4 |
| Norfolk | 60 | | 40 | | | 1.3** | 5 |
| Jacksonville | | 60 | 30 | | 5 | | 6 |
| Sand | | | | | | 1† | |
| Silts and clays | | | | | | 2† | |
| Philadelphia | 25 | 10 | 20 | | 45 | 0.67 | 7 |
| Savannah | 65 | 15 | 20 | | | 0.5 | 8 |
| Baltimore | 90 | 5 | | | 5 | 1.6-1.7 | 9 |

* Considers overdredging.

** Considers 30 percent overdredging, no bulking factor.

† Considers swelling during discharge, overdredging, and ponding time.

Table 3

Bulking and Design Factors According to Material

| Material | Dry Density, lb/cu ft: In Situ, $\gamma_d^{in}$ (Reference 10) | Dry Density, lb/cu ft: Sedimented, $\gamma_d^{ca}$ (Reference 11) | Bulking Factors: Equation 1b | Bulking Factors: Reference 12 |
|---|---|---|---|---|
| Clay | 94* | 30–78 | 1.2–3.1 | 1.45 |
| Sandy clay | 94* | | | 1.25 |
| Silt | 94* | 65–82 | 1.1–1.4 | 2.0 |
| Sand | 90–110 | 93 | 1.0–1.2 | 1.0 |
| Gravel | 110 | | | 1.75 |
| Quartz (rock) | 165 | 93 | 1.8 | 1.75 |

* Dry density of packed dry earth.

Table 4

Properties of Containment Area Soils

| Material | Parameter | Quantity | Units |
| --- | --- | --- | --- |
| | | Dredged Clay Slurry[44] | |
| Clay slurry | $c_v$ | $2.0 - 0.45 \log_{10} \Delta\bar{\sigma}_v$ | sq in./day |
| | $m_v$ | $0.125 - 0.08 \log_{10} \Delta\bar{\sigma}_v$ | sq in./lb |
| | k | $\log_{10}^{-1} (-5.9 - 1.4 \log_{10} \Delta\bar{\sigma}_v)$ | cm/sec |
| | $\gamma_d$* | 46.0 | lb/cu ft |
| | $G_s$ | 2.65 | |
| | $\Delta\bar{\sigma}_v$ | Effective pressure | lb/sq in. |
| | | Foundation Soil | |
| Silt | $c_v$ | 288 | sq in./day |
| | $m_v$ | 0.001 | sq in./lb |
| | k | $3.0 \times 10^{-7}$ | cm/sec |
| Clay | $c_v$ | 1.5 | sq in./day |
| | $m_v$ | 0.007 | sq in./lb |
| | k | $1.1 \times 10^{-8}$ | cm/sec |

* $\gamma_d$ is 33.1 lb/cu ft for the deposited dredged material of the example problem in Part III based on the inflection point void ratio of 4.0 and a specific gravity of 2.65.

Table 5

Properties of a Deposited Sediment

| Property | Quantity | Units |
|---|---|---|
| Dry density, $\gamma_d$ | 46 | lb/cu ft |
| Specific gravity, $G_s$ | 2.65 | |
| Submerged unit weight, $\gamma_b$ | 28.6 | lb/cu ft |
| Average effective stress, $\Delta\bar{\sigma}_v$ | $\left(\frac{\gamma_b H}{2}\right)\left(\frac{1}{144}\right)$ | lb/sq in. |
| Average coefficient of volume change, $m_v$ | $0.125 - 0.08 \log_{10} \Delta\bar{\sigma}_v$ | sq in./lb (Reference 44) |
| Average coefficient of consolidation, $c_v$ | 1.5 | sq in./day |
| Sediment depth, H | Variable | ft |

## APPENDIX A: METHOD FOR EVALUATING SEDIMENTATION RATES OF SUSPENDED SOLIDS IN SLURRY OF DREDGED MATERIAL

1. The void ratio of a depositing sediment can be estimated as a function of time (a) by evaluating the settling velocity of the suspended particles as a function of void ratio and (b) by introducing the continuity condition.

### Settling Velocity of Suspended Particles

2. On the basis of Stokes's law, the steady-state motion of a spherical particle can be given by[47*]

$$\frac{C_D a^2 \pi \rho (v_s - v)^2}{2} = \frac{4\pi a^3 (\rho_s - \rho) g}{3} \tag{A1}$$

where

$C_D$ = drag coefficient
$a$ = radius of particle, L
$\rho$ = density of liquid phase, $ML^{-3}$
$v_s$ = velocity of solid particles, $LT^{-1}$
$v$ = velocity of the liquid phase, $LT^{-1}$
$\rho_s$ = density of solid particles, $ML^{-3}$
$g$ = acceleration of gravity, $LT^{-2}$

3. For a small-diameter sphere moving slowly at a constant velocity in an infinite viscous liquid, i.e., the motion of a dust particle in a thick slurry with a Reynolds number of less than one, the drag force becomes significant and may be given by[47]

$$R = 6\pi\mu a v_s \tag{A2}$$

* Superscript numbers refer to similarly numbered items in the References at end of the main text.

where

$R$ = drag on the particle, $MLT^{-2}$

$\mu$ = viscosity of the liquid, $MT^{-1}L^{-1}$

4. The drag is related to the drag coefficient by

$$R = C_D A_p \rho \frac{v_s^2}{2} \tag{A3}$$

where $A_p$ represents the projected area of the particle in the direction of flow.

5. Complicating factors, which include particle shape, boundary conditions, multiparticle influences, particle rotation and roughness, turbulence, and combinations of these factors, alter the drag on the particles such that[47]

$$R = K\ (6\pi\mu a v_s) \tag{A4}$$

where $K$ is the correction factor in settling velocity theory.

6. If the vertical velocity of the liquid phase is assumed to be zero, substitution of Equations A3 and A4 into Equation A1 will give for the settling velocity of the solid particles

$$v_s = \frac{2A_p(\rho - \rho_s)g}{9\pi K\mu} \tag{A5}$$

7. The effect of the particle concentration on the correction factor $K$ has been given by an empirical equation of the form[47,48]

$$K = (1 - C)^{-m} \tag{A6}$$

where

$C$ = concentration per volume of the solid particles

$m$ = value 4.5 for Reynolds number less than one

8. By inserting Equation A6 into Equation A5 and noting that the porosity $n$ is equal to $1 - C$, Equation A5 reduces to

$$v_s = \bar{A}n^m \tag{A7}$$

where

$$\bar{A} = \frac{2A_p \gamma_w (G_s - G)}{9\pi\mu} \text{ , } LT^{-1}$$

$\gamma_w$ = unit weight of water, $ML^{-2}T^{-2}$

$G_s$ = specific gravity of solids

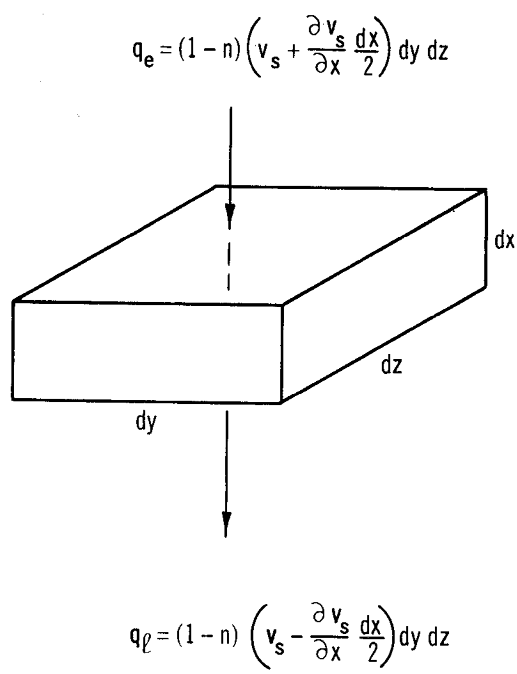
$G$ = specific gravity of liquid

The values of parameter $\bar{A}$ and exponent $m$ of Equation A7 may be adjusted empirically for better correlation with actual observed field measurements of settling velocity as a function of the porosity of given suspensions.

## Continuity Condition

9. During sedimentation, the difference in the volume of solids entering and leaving an infinitesimal volume per unit time, $q_e$ and $q_\ell$, respectively (Figure A1), is considered to equal the change in

Figure A1. Volume rate of solids entering and leaving an infinitesimal volume of slurry



volume of water per unit time of the same infinitesimal volume; that is,

$$\frac{\partial V_w}{\partial t} = q_e - q_\ell \tag{A8}$$

where

$V_w$ = volume of water, $L^3$

$t$ = time, $T$

The change in volume of water per unit time in terms of porosity $n$ is

$$\frac{\partial V_w}{\partial t} = \frac{\partial eV_s}{\partial t} = \left(\frac{\partial n}{\partial t}\right) dx\ dy\ dz \tag{A9}$$

where

$e$ = void ratio

$V_s$ = volume of solids, $L^3$

$n = e/(1 + e)$

The volume of solids entering or leaving the unit volume per unit time is

$$q_e = (1 - n)\left(v_s + \frac{\partial v_s}{\partial x}\ \frac{dx}{2}\right) dy\ dz \tag{A10}$$

$$q_\ell = (1 - n)\left(v_s - \frac{\partial v_s}{\partial x}\ \frac{dx}{2}\right) dy\ dz \tag{A11}$$

The factor $(1 - n)$ in Equations A10 and A11 corrects the infinitesimal volume $(dx\ dy\ dz)$ for the proportion of total volume occupied by the solid particles.

10. Substituting Equations A9, A10, and A11 into Equation A8 results in

$$\frac{\partial n}{\partial t} = (1 - n)\ \frac{\partial v_s}{\partial x} \tag{A12}$$

11. Incorporating Equation A12 in Equation A7 yields

$$\frac{\partial n}{\partial t} = \overline{A}(1 - n)\ \frac{\partial n^{4.5}}{\partial x} \tag{A13}$$

12. Equation A13 may then be solved by a finite difference approximation

$$\frac{n_i^{t+1} - n_i^t}{\Delta t} = \frac{\overline{A}\,\overline{B}}{\Delta x}\left(P_{i+1}^t - P_i^t\right) \tag{A14}$$

where

$n_i^t$ = porosity at location $i$ and time $t$ (Figure 4 of main text)

$t$ = incremental change in time $t$ (Figure 4 of main text)

$x$ = incremental change in depth $x$ (Figure 4 of main text)

$$\overline{B} = \frac{\left(1 - n_i^t\right) + \left(1 - n_{i+1}^t\right)}{2}$$

$P = n^{4.5}$

13. Solution of Equation A14 requires knowledge of the porosity or dry density of the sediment following sedimentation, but prior to any consolidation that may occur from other processes such as primary consolidation. These data are among those being sought by the analysis and are usually not available. An approximation of the ultimate porosity or dry density, however, may be made on the basis of past experience to determine a useful relationship of the porosity of depositing sediment as a function of time.

14. Lane and Koelzer[11] evaluated the dry densities of various sediments from numerous field data of sediments in streams and reservoirs. Analysis of the field data indicated that for ponded areas where the sediments may be frequently exposed by changes in the water level, the dry density at the end of one year following sedimentation may be given for silt by 74 lb/cu ft and for clay by 46 lb/cu ft. The dry density of sand remained fairly constant at about 93 lb/cu ft. These dry densities were taken as reasonable estimates of sediment densities that would have occurred without significant consolidation by other processes. Following sedimentation, the dry density of sediment is not expected to change significantly from consolidation processes within a relatively short time span of about 1 yr. Silts were defined by Lane and Koelzer[11] as particles with diameters from 0.005 mm to 0.05 mm, while clays were described as particles with diameters less than 0.005 mm.

15. Evaluation of computations from the solution of Equation A14 for the above limiting dry densities from sedimentation lead to the approximate relationship given by Equation 4. Assumptions made in derivation of Equations A14 and 4 include these factors:

- a. Horizontal flow velocities are zero.
- b. Particles flow vertically downward.
- c. Vertical velocity of the liquid phase is zero.
- d. Volume of solids entering a unit volume equals the volume of water leaving the unit volume.
- e. Dry densities of clay and silt sediments following sedimentation in the containment area are approximately 46 and 74 lb/cu ft, respectively.
- f. The average particle diameter can be given by the diameter at which 50 percent are finer by weight.
- g. All of the slurry particles will eventually drop to the bed.

A further limitation of the above derivations is inherent with the use of Stokes's law, which assumes a uniform particle size. The range in particle size should be 0.0002 to 0.2 mm.[49] The specific gravity of solids was taken as 2.65, and the viscosity of water was given as $0.21 \times 10^{-4}$ lb-sec/sq ft for a temperature of 20 deg C (68 deg F). A more complete discussion of the sedimentation theory is given by Dr. B. H. Johnson in Reference 50.

16. The theory also neglects the distribution in slurry grain size throughout the containment area. The coarse particles should settle out more quickly near the input pipe, while the fine sediment should accumulate close to the discharge area. Changing the location of the input and discharge areas may reduce the variation in grain-size distribution within the containment area and lead to more uniform bed sediment. The containment area ground surface should be fairly level to minimize horizontal velocities. Some of the above assumptions may restrict applicability of Equations A14 and 4 for various sediments and disposal operations.

# APPENDIX B: FINITE DIFFERENCE CODE FOR CONSOLIDATION OF DREDGED MATERIAL AND FOUNDATION SOIL

## Purpose

1. The purpose of the computer program is to evaluate the one-dimensional (1-D) settlement of dredged material and heterogeneous foundation soil in confined containment areas in support of methodology for predicting the capacity of confined dredged material disposal areas. The computer code contains provisions to permit settlement predictions for (a) dredged material that increases in thickness with time from periodic disposal operations and (b) variations in time intervals between disposal operations.

## Approach

2. The 1-D settlements of dredged material and foundation soil are calculated on the basis of the dissipation of excess pore water pressure according to standard theory of 1-D primary consolidation.[21,49,51] A special explicit finite difference numerical technique[42] was applied to solve the 1-D differential equation (Equation 17 of main text) for primary consolidation. The numerical technique permits versatile boundary conditions that may be reasonably representative of actual field conditions for confinement of dredged material.

## Capabilities

3. The computer program was prepared for time sharing on the WES GE-600 computer. The code is capable of computing the excess pore pressure distribution, average degree of consolidation, and settlement of dredged material and layered (heterogeneous) foundation soil strata of flooded containment areas. Time intervals for placement of dredged material during a single disposal operation and between disposal operations may be varied.

4. The consolidation parameters of the dredged material may be input as a function of the effective stress to permit improved simulation of actual field conditions. The consolidation parameters of the foundation soils are assumed constant.

5. A variety of dredging operations spaced at various time intervals may be handled by the code in a single computer run provided that the dredged material being placed is homogeneous with identical consolidation parameters. The consolidation behavior of dredged material and foundation soils may be calculated for a number of dredging operations involving different dredged material if (a) a single computer run of the code is used to solve for the consolidation behavior of the soil system for each disposal operation and (b) the initial excess pore pressures are input from a file named EXCESS through option LOPT of the code. The dredged material deposited during the previous disposal operation may be treated as the surface layer of foundation soils (with constant consolidation parameters) for the current disposal operation.

## Organization

6. The computer code named PROCON directs the computer to read the input data from a file named DATA. The 1-D mesh is subsequently computed from the input data (Figure B1). The vertical scale of the 1-D mesh in the figure is expanded in the layers of dredged material to illustrate these layers more clearly for the example problem detailed in Part III of the main text.

7. The magnitude of the initial excess pore water pressures is determined by the option LOPT. The value LOPT equals zero is used for a computer run with multiple dredging operations involving a single dredged material of identical consolidation parameters and for new disposal areas where initial excess pore water pressures may be assumed zero. To evaluate the consolidation behavior of a freshly placed layer of dredged material and foundation soils in a disposal area where the initial excess pore pressures are known or were previously calculated by a prior computer run with the code, the value LOPT equals two is

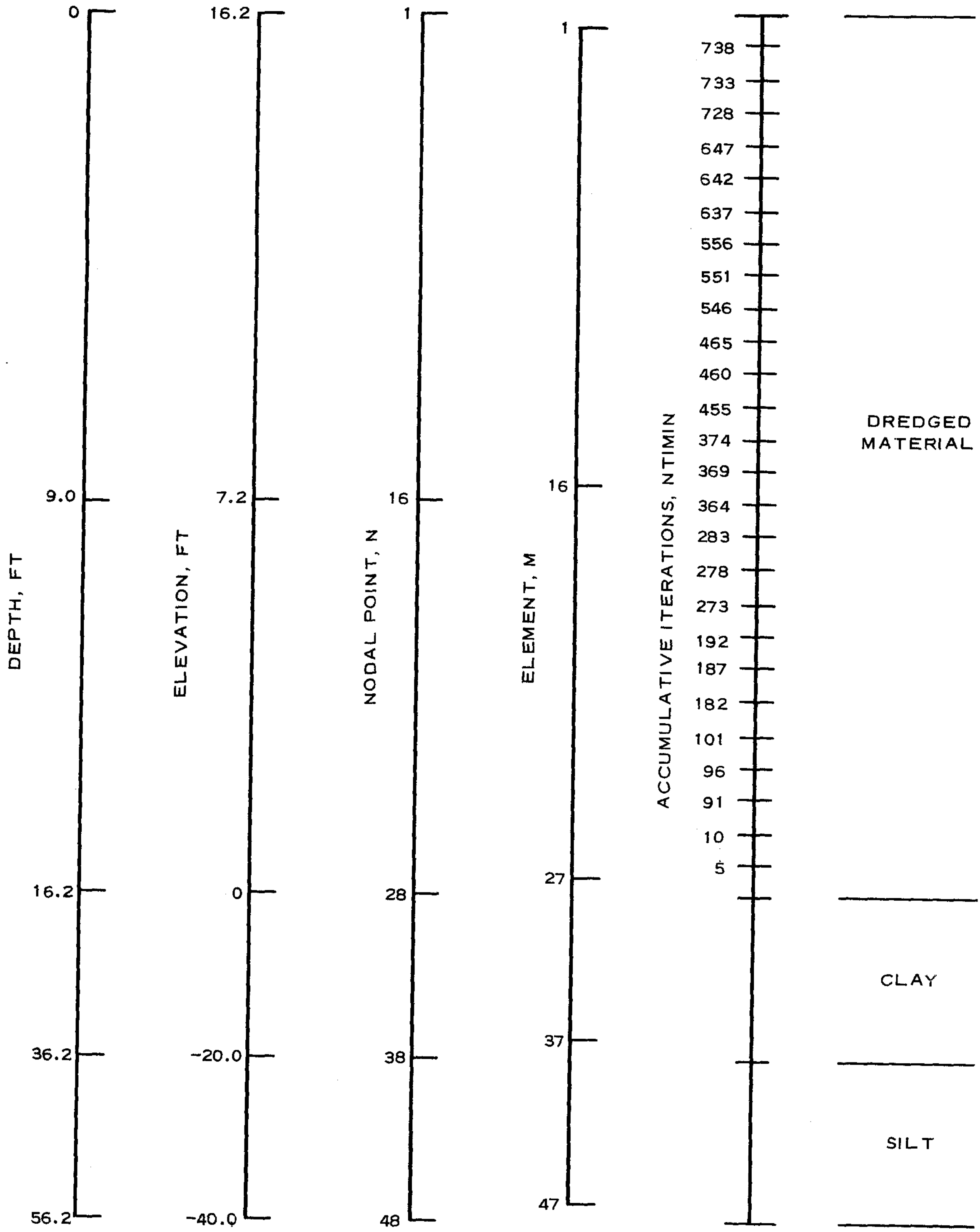



Figure B1. Mesh for example problem

used. The initial pore water pressures are read from a permanent file called EXCESS.

8. The excess pore pressures caused by the submerged weight of the first layer of dredged material are initially calculated by the computer. The code subsequently directs the computer to calculate the dissipation of the excess pore pressures with time by the special explicit finite difference technique,[42] until the computer is directed by the input data to add the excess pore pressures caused by the submerged weight of a subsequent layer of dredged material of identical composition as the previous layer. The cycle of computation of excess pore pressure dissipation and increase in excess pore pressure due to placement of an additional layer of dredged material continues until the computer is directed to record the excess pore pressure distribution, average degree of consolidation, and settlements of the dredged material and foundation soil system.

9. The code directs the computer to write the output data on a permanent file called JATA. The output on JATA may be printed out on the WES high-speed printer by direction from the time-sharing terminal.

10. The final excess pore water pressure distribution remaining at the conclusion of the computer run is recorded on the permanent file EXCESS if LOPT equals one or two. The value LOPT equals one is used if the initial excess pore water pressure distribution is zero; the value LOPT equals two is used if the initial excess pore water pressures must be read from EXCESS at the beginning of the computer run.

## Input Data

11. The input data should be saved in a file named DATA in the following order:

| Statement Number | Variable Names |
|---|---|
| 100 | NTIME, (NOUT(I), I = 1, NTIME) |
| 110 | NNP, NMAT, DT |

(Continued)

| Statement Number | Variable Names |
|---|---|
| 120 | SPGR, DDEN, AMV, BMV, ACV, BCV, APER, BPER |
| 130 | NDROP, (NTIMIN(I), I = 1, NDROP) |
| 140 | NDNP, NOPT, MOPT |
| 150 | (PERM(I), I = 2, NMAT), (CV(I), I = 2, NMAT) |
| 160 | (DMV(I), I = 2, NMAT) |
| 170 | 1, 0.0 |
| 180 | N, X(N) |
| | to |
| 200 | NNP, X(NNP) |
| 210 | 1, 1, 2, 1 |
| 220 | M, (IX(M,I), I = 1, 3) |
| | to |
| 250 | NEL, NEL, NNP, NMAT |

12. The variable names are defined as follows:

| | |
|---|---|
| NTIME | Total number of times for output data. |
| NOUT(I) | Iterations specified for output data up to I = NTIME . |
| NNP | Total number of nodal points for entire mesh. Mesh (1-D) includes space for placement of dredged material. Nodal point numbers increase with increasing depth. |
| NMAT | Total number of materials. Material I = 1 is the dredged material. Materials I = 2 to I = NMAT are foundation soils. |
| DT | Time interval for each cycle or iteration, days. |
| SPGR | Specific gravity of the dredged material. |
| DDEN | Dry density of the dredged material, lb/cu ft. |
| AMV, BMV | Parameters for the coefficient of volume change of dredged material, DMV(1), sq in./lb. DMV(1) = AMV + BMV $\log_{10}$ P , where P is the effective pressure, lb/sq in. |
| ACV, BCV | Parameters for the coefficient of consolidation of dredged material, CV(1), sq in./day. CV(1) = ACV + BCV $\log_{10}$ P , where P is the effective pressure, lb/sq in. |

| | |
|---|---|
| APER, BPER | Parameters for the coefficient of permeability of dredged material, PERM(1), cm/sec. PERM(1) = APER + BPER $\log_{10}$ P where P is the effective pressure, lb/sq in. |
| NDROP | Total number of times that dredged material is deposited. |
| NTIMIN(I) | Accumulative number of iterations when layer I is deposited. |
| NDNP | Nodal point number of the foundation soil and dredged material interface. |
| NOPT | Option for double ( = 1) or surface ( = 0) drainage. Double drainage occurs from the surface of the dredged material and bottom of the foundation soil. The foundation soil is assumed on a pervious base. Surface drainage occurs only from the surface of the dredged material. The foundation soil is on an impervious base. |
| MOPT | Option to print the excess pore pressure distribution ( = 1) or eliminate printout of the excess pore pressure distribution ( = 0). |
| LOPT | Option to write on file EXCESS the excess pore pressures at the conclusion of the run and/or to read from file EXCESS the initial excess pore pressures prior to the run. ( = 0) will not read or write excess pore pressures; ( = 1) will write excess pore pressures at end of run on file EXCESS; and ( = 2) will read initial excess pore pressures from file EXCESS at start of run and write excess pore pressures at end of run on file EXCESS. |
| PERM(I) | Coefficient of permeability of material I, cm/sec. PERM(1) is the permeability of the dredged material. |
| CV(I) | Coefficient of consolidation of material I, sq in./day. CV(1) is the coefficient of consolidation of the dredged material. |
| DMV(I) | Coefficient of volume change of material I, sq in./lb. DMV(1) is the coefficient of volume change of the dredged material. |
| X(N) | Depth of each nodal point number N, ft. The computer computes the X(N) for equally spaced nodal points. Only the first and last nodal point numbers and depths need to be input for equally spaced depth intervals. |
| IX(M, I) | For each element M<br>I = 1 put M up to NEL<br>I = 2 put M + 1 up to NEL<br>I = 3 put material number between nodes M and M + 1. The computer computes IX(M, I) for elements of identical material number IX(M, 3). The first and last elements of a series of elements with constant material type should be input. |
| NEL | Total number of elements, NNP - 1. |

NCT Accumulative number of iterations when output is specified.

13. The listing of the input data for the example problem in Part III is as follows:

```
100  24,2,5,8,10,40,80,91,150,182,250,273,330,364,400,455,500,
110  546,600,637,680,738,819,910,1001
120  48,3,4
130  2.65,33.1,.125,-.08,2.0,-.45,-5.9,-1.4
140  26,5,10,91,96,101,182,187,192,273,278,283,364,369,374,455,
150  460,465,546,551,556,637,642,647,728,733,738
160  28,1,1
170  1.1E-08,3.0E-07,1.5,288.
180  .007,.001
190  1,0.0
200  28,16.2
210  48,56.2
220  1,1,2,1
230  27,27,28,1
240  28,28,29,2
250  37,37,38,2
260  38,38,39,3
270  47,47,48,3
280  0,0,0,0,0,0,0,0,0,0
```

## Output Data

14. The output data are recorded on file JATA in two tables:

Table 1

Data for Each Nodal Point

| Nodal Point N | Excess Pore Water Pressure, lb/sq in. U(N) | Settlement, in. SET | Ultimate Settlement, in. ULTSET |
|---|---|---|---|

Table 2

Data for the Soil System

| | | Average Degree of Consolidation | | Settlement, in. | |
|---|---|---|---|---|---|
| Accumulative Time Increment NCT | Time days TIME | Dredged Material U OF DM | Foundation Soil U OF FS | Dredged Material SET DM | Foundation Soil SET FS |

The output of both Tables 1 and 2 is printed if MOPT is set equal to one; however, only Table 2 is printed if MOPT is set equal to zero.

15. The listing of the output data of the example problem in Part III is as follows:

```
 1551T 01   03-06-75    07.775

 NNP DEPTH,FT   U,PSI        SET,IN.     ULTSET,IN
   28   0.6   0.6790E-01   0.3032E-01   0.1449E 00
   29   2.6   0.8559E-01   0.3037E-01   0.1593E 00
   30   4.6   0.8587E-01   0.3037E-01   0.1738E 00
   31   6.6   0.8587E-01   0.3037E-01   0.1882E 00
   32   8.6   0.8587E-01   0.3037E-01   0.2026E 00
   33  10.6   0.8587E-01   0.3037E-01   0.2170E 00
   34  12.6   0.8587E-01   0.3037E-01   0.2315E 00
   35  14.6   0.8587E-01   0.3037E-01   0.2459E 00
   36  16.6   0.8587E-01   0.3037E-01   0.2603E 00
   37  18.6   0.8587E-01   0.3037E-01   0.2747E 00
   38  20.6   0.8587E-01   0.3037E-01   0.2892E 00
   39  22.6   0.8587E-01   0.3037E-01   0.2912E 00
   40  24.6   0.8587E-01   0.3037E-01   0.2933E 00
   41  26.6   0.8587E-01   0.3037E-01   0.2954E 00
   42  28.6   0.8587E-01   0.3037E-01   0.2974E 00
   43  30.6   0.8587E-01   0.3037E-01   0.2995E 00
   44  32.6   0.8587E-01   0.3037E-01   0.3015E 00
   45  34.6   0.8587E-01   0.3037E-01   0.3036E 00
   46  36.6   0.4771E-01   0.3129E-01   0.3057E 00
   47  38.6   0.2226E-01   0.3281E-01   0.3077E 00
   48  40.6   0.           0.3487E-01   0.3098E 00

 NCT    TIME,DAYS    U OF DM      U OF FS      SET DM,IN.   SET FS,IN.
   2   0.8000E 01   0.2092E 00   0.2761E-01   0.3032E-01   0.4551E-02

 NNP DEPTH,FT   U,PSI        SET,IN.     ULTSET,IN
   28   0.6   0.4775E-01   0.6433E-01   0.1449E 00
   29   2.6   0.8464E-01   0.6454E-01   0.1593E 00
   30   4.6   0.8584E-01   0.6455E-01   0.1738E 00
   31   6.6   0.8587E-01   0.6455E-01   0.1882E 00
   32   8.6   0.8587E-01   0.6455E-01   0.2026E 00
   33  10.6   0.8587E-01   0.6455E-01   0.2170E 00
   34  12.6   0.8587E-01   0.6455E-01   0.2315E 00
   35  14.6   0.8587E-01   0.6455E-01   0.2459E 00
   36  16.6   0.8587E-01   0.6455E-01   0.2603E 00
   37  18.6   0.8587E-01   0.6455E-01   0.2747E 00
   38  20.6   0.8587E-01   0.6455E-01   0.2892E 00
   39  22.6   0.8587E-01   0.6455E-01   0.2912E 00
   40  24.6   0.8587E-01   0.6455E-01   0.2933E 00
   41  26.6   0.8587E-01   0.6455E-01   0.2954E 00
   42  28.6   0.8587E-01   0.6455E-01   0.2974E 00
   43  30.6   0.7456E-01   0.6482E-01   0.2995E 00
   44  32.6   0.6137E-01   0.6541E-01   0.3015E 00
   45  34.6   0.4629E-01   0.6636E-01   0.3036E 00
   46  36.6   0.3048E-01   0.6769E-01   0.3057E 00
   47  38.6   0.1484E-01   0.6939E-01   0.3077E 00
   48  40.6   0.           0.7145E-01   0.3098E 00
```

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| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN. | SET FS,IN. |
|---|---|---|---|---|---|
| 5 | 0.2000E 02 | 0.4440E 00 | 0.4317E-01 | 0.6433E-01 | 0.7117E-02 |

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 27 | 0.6 | 0.4077E-01 | 0.7610E-01 | 0.2898E 00 |
| 28 | 1.2 | 0.1118E 00 | 0.1608E 00 | 0.5324E 00 |
| 29 | 3.2 | 0.1690E 00 | 0.1613E 00 | 0.5613E 00 |
| 30 | 5.2 | 0.1716E 00 | 0.1613E 00 | 0.5901E 00 |
| 31 | 7.2 | 0.1717E 00 | 0.1613E 00 | 0.6190E 00 |
| 32 | 9.2 | 0.1717E 00 | 0.1613E 00 | 0.6479E 00 |
| 33 | 11.2 | 0.1717E 00 | 0.1613E 00 | 0.6767E 00 |
| 34 | 13.2 | 0.1717E 00 | 0.1613E 00 | 0.7056E 00 |
| 35 | 15.2 | 0.1717E 00 | 0.1613E 00 | 0.7344E 00 |
| 36 | 17.2 | 0.1717E 00 | 0.1613E 00 | 0.7633E 00 |
| 37 | 19.2 | 0.1717E 00 | 0.1613E 00 | 0.7921E 00 |
| 38 | 21.2 | 0.1717E 00 | 0.1613E 00 | 0.8210E 00 |
| 39 | 23.2 | 0.1717E 00 | 0.1613E 00 | 0.8251E 00 |
| 40 | 25.2 | 0.1684E 00 | 0.1614E 00 | 0.8292E 00 |
| 41 | 27.2 | 0.1628E 00 | 0.1616E 00 | 0.8333E 00 |
| 42 | 29.2 | 0.1550E 00 | 0.1620E 00 | 0.8375E 00 |
| 43 | 31.2 | 0.1453E 00 | 0.1626E 00 | 0.8416E 00 |
| 44 | 33.2 | 0.1343E 00 | 0.1635E 00 | 0.8457E 00 |
| 45 | 35.2 | 0.9688E-01 | 0.1653E 00 | 0.8498E 00 |
| 46 | 37.2 | 0.6337E-01 | 0.1679E 00 | 0.8539E 00 |
| 47 | 39.2 | 0.3060E-01 | 0.1713E 00 | 0.8581E 00 |
| 48 | 41.2 | 0. | 0.1754E 00 | 0.8622E 00 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN. | SET FS,IN. |
|---|---|---|---|---|---|
| 8 | 0.3200E 02 | 0.3021E 00 | 0.4433E-01 | 0.1608E 00 | 0.1462E-01 |

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 27 | 0.6 | 0.2857E-01 | 0.9670E-01 | 0.2898E 00 |
| 28 | 1.2 | 0.9635E-01 | 0.2032E 00 | 0.5324E 00 |
| 29 | 3.2 | 0.1676E 00 | 0.2039E 00 | 0.5613E 00 |
| 30 | 5.2 | 0.1716E 00 | 0.2039E 00 | 0.5901E 00 |
| 31 | 7.2 | 0.1717E 00 | 0.2039E 00 | 0.6190E 00 |
| 32 | 9.2 | 0.1717E 00 | 0.2039E 00 | 0.6479E 00 |
| 33 | 11.2 | 0.1717E 00 | 0.2039E 00 | 0.6767E 00 |
| 34 | 13.2 | 0.1717E 00 | 0.2039E 00 | 0.7056E 00 |
| 35 | 15.2 | 0.1717E 00 | 0.2039E 00 | 0.7344E 00 |
| 36 | 17.2 | 0.1717E 00 | 0.2039E 00 | 0.7633E 00 |
| 37 | 19.2 | 0.1717E 00 | 0.2039E 00 | 0.7921E 00 |
| 38 | 21.2 | 0.1717E 00 | 0.2039E 00 | 0.8210E 00 |
| 39 | 23.2 | 0.1682E 00 | 0.2040E 00 | 0.8251E 00 |
| 40 | 25.2 | 0.1632E 00 | 0.2042E 00 | 0.8292E 00 |
| 41 | 27.2 | 0.1567E 00 | 0.2046E 00 | 0.8333E 00 |
| 42 | 29.2 | 0.1487E 00 | 0.2051E 00 | 0.8375E 00 |
| 43 | 31.2 | 0.1281E 00 | 0.2062E 00 | 0.8416E 00 |
| 44 | 33.2 | 0.1048E 00 | 0.2078E 00 | 0.8457E 00 |
| 45 | 35.2 | 0.7895E-01 | 0.2100E 00 | 0.8498E 00 |

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| | | | | |
|---|---|---|---|---|
| 46 | 37.2 | 0.5214E-01 | 0.2129E 00 | 0.8539E 00 |
| 47 | 39.2 | 0.2554E-01 | 0.2164E 00 | 0.8581E 00 |
| 48 | 41.2 | 0. | 0.2205E 00 | 0.8622E 00 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN, | SET FS,IN, |
|---|---|---|---|---|---|
| 10 | 0.4000E 02 | 0.3816E 00 | 0.5250E-01 | 0.2032E 00 | 0.1731E-01 |

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 26 | 0.6 | 0.3910E-02 | 0.1383E 00 | 0.2898E 00 |
| 27 | 1.2 | 0.1856E-01 | 0.3547E 00 | 0.6773E 00 |
| 28 | 1.8 | 0.3912E-01 | 0.6403E 00 | 0.1019E 01 |
| 29 | 3.8 | 0.2153E 00 | 0.6474E 00 | 0.1063E 01 |
| 30 | 5.8 | 0.2519E 00 | 0.6484E 00 | 0.1106E 01 |
| 31 | 7.8 | 0.2570E 00 | 0.6485E 00 | 0.1149E 01 |
| 32 | 9.8 | 0.2576E 00 | 0.6485E 00 | 0.1192E 01 |
| 33 | 11.8 | 0.2576E 00 | 0.6485E 00 | 0.1236E 01 |
| 34 | 13.8 | 0.2576E 00 | 0.6485E 00 | 0.1279E 01 |
| 35 | 15.8 | 0.2576E 00 | 0.6485E 00 | 0.1322E 01 |
| 36 | 17.8 | 0.2575E 00 | 0.6485E 00 | 0.1366E 01 |
| 37 | 19.8 | 0.2565E 00 | 0.6487E 00 | 0.1409E 01 |
| 38 | 21.8 | 0.2467E 00 | 0.6506E 00 | 0.1452E 01 |
| 39 | 23.8 | 0.2226E 00 | 0.6514E 00 | 0.1458E 01 |
| 40 | 25.8 | 0.1983E 00 | 0.6528E 00 | 0.1464E 01 |
| 41 | 27.8 | 0.1738E 00 | 0.6548E 00 | 0.1471E 01 |
| 42 | 29.8 | 0.1492E 00 | 0.6574E 00 | 0.1477E 01 |
| 43 | 31.8 | 0.1244E 00 | 0.6606E 00 | 0.1483E 01 |
| 44 | 33.8 | 0.9959E-01 | 0.6644E 00 | 0.1489E 01 |
| 45 | 35.8 | 0.7471E-01 | 0.6688E 00 | 0.1495E 01 |
| 46 | 37.8 | 0.4980E-01 | 0.6738E 00 | 0.1502E 01 |
| 47 | 39.8 | 0.2488E-01 | 0.6794E 00 | 0.1508E 01 |
| 48 | 41.8 | 0. | 0.6856E 00 | 0.1514E 01 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN, | SET FS,IN, |
|---|---|---|---|---|---|
| 40 | 0.1600E 03 | 0.6282E 00 | 0.9146E-01 | 0.6403E 00 | 0.4524E-01 |

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 26 | 0.6 | 0.4345E-03 | 0.1442E 00 | 0.2898E 00 |
| 27 | 1.2 | 0.2069E-02 | 0.3839E 00 | 0.6773E 00 |
| 28 | 1.8 | 0.4380E-02 | 0.7141E 00 | 0.1019E 01 |
| 29 | 3.8 | 0.1659E 00 | 0.7295E 00 | 0.1063E 01 |
| 30 | 5.8 | 0.2338E 00 | 0.7335E 00 | 0.1106E 01 |
| 31 | 7.8 | 0.2528E 00 | 0.7343E 00 | 0.1149E 01 |
| 32 | 9.8 | 0.2568E 00 | 0.7345E 00 | 0.1192E 01 |
| 33 | 11.8 | 0.2575E 00 | 0.7345E 00 | 0.1236E 01 |
| 34 | 13.8 | 0.2576E 00 | 0.7345E 00 | 0.1279E 01 |
| 35 | 15.8 | 0.2575E 00 | 0.7345E 00 | 0.1322E 01 |
| 36 | 17.8 | 0.2565E 00 | 0.7347E 00 | 0.1366E 01 |
| 37 | 19.8 | 0.2510E 00 | 0.7358E 00 | 0.1409E 01 |
| 38 | 21.8 | 0.2286E 00 | 0.7407E 00 | 0.1452E 01 |
| 39 | 23.8 | 0.2061E 00 | 0.7420E 00 | 0.1458E 01 |

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| | | | | |
|---|---|---|---|---|
| 40 | 25.8 | 0.1836E 00 | 0.7437E 00 | 0.1464E 01 |
| 41 | 27.8 | 0.1608E 00 | 0.7461E 00 | 0.1471E 01 |
| 42 | 29.8 | 0.1380E 00 | 0.7489E 00 | 0.1477E 01 |
| 43 | 31.8 | 0.1151E 00 | 0.7523E 00 | 0.1483E 01 |
| 44 | 33.8 | 0.9213E-01 | 0.7563E 00 | 0.1489E 01 |
| 45 | 35.8 | 0.6911E-01 | 0.7608E 00 | 0.1495E 01 |
| 46 | 37.8 | 0.4606E-01 | 0.7659E 00 | 0.1502E 01 |
| 47 | 39.8 | 0.2302E-01 | 0.7715E 00 | 0.1508E 01 |
| 48 | 41.8 | 0. | 0.7777E 00 | 0.1514E 01 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN, | SET FS,IN, |
|---|---|---|---|---|---|
| 80 | 0.3200E 03 | 0.7006E 00 | 0.1286E 00 | 0.7141E 00 | 0.6360E-01 |

| NNP | DEPTH,FT | U,PSI | SET,IN, | ULTSET,IN |
|---|---|---|---|---|
| 26 | 0.6 | 0.2392E-03 | 0.1445E 00 | 0.2898E 00 |
| 27 | 1.2 | 0.1141E-02 | 0.3855E 00 | 0.6773E 00 |
| 28 | 1.8 | 0.2422E-02 | 0.7183E 00 | 0.1019E 01 |
| 29 | 3.8 | 0.1559E 00 | 0.7354E 00 | 0.1063E 01 |
| 30 | 5.8 | 0.2281E 00 | 0.7403E 00 | 0.1106E 01 |
| 31 | 7.8 | 0.2509E 00 | 0.7414E 00 | 0.1149E 01 |
| 32 | 9.8 | 0.2564E 00 | 0.7417E 00 | 0.1192E 01 |
| 33 | 11.8 | 0.2574E 00 | 0.7417E 00 | 0.1236E 01 |
| 34 | 13.8 | 0.2576E 00 | 0.7417E 00 | 0.1279E 01 |
| 35 | 15.8 | 0.2573E 00 | 0.7417E 00 | 0.1322E 01 |
| 36 | 17.8 | 0.2559E 00 | 0.7420E 00 | 0.1366E 01 |
| 37 | 19.8 | 0.2490E 00 | 0.7435E 00 | 0.1409E 01 |
| 38 | 21.8 | 0.2239E 00 | 0.7492E 00 | 0.1452E 01 |
| 39 | 23.8 | 0.2019E 00 | 0.7505E 00 | 0.1458E 01 |
| 40 | 25.8 | 0.1798E 00 | 0.7524E 00 | 0.1464E 01 |
| 41 | 27.8 | 0.1575E 00 | 0.7548E 00 | 0.1471E 01 |
| 42 | 29.8 | 0.1352E 00 | 0.7577E 00 | 0.1477E 01 |
| 43 | 31.8 | 0.1127E 00 | 0.7612E 00 | 0.1483E 01 |
| 44 | 33.8 | 0.9023E-01 | 0.7652E 00 | 0.1489E 01 |
| 45 | 35.8 | 0.6769E-01 | 0.7698E 00 | 0.1495E 01 |
| 46 | 37.8 | 0.4512E-01 | 0.7749E 00 | 0.1502E 01 |
| 47 | 39.8 | 0.2255E-01 | 0.7805E 00 | 0.1508E 01 |
| 48 | 41.8 | 0. | 0.7867E 00 | 0.1514E 01 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN, | SET FS,IN, |
|---|---|---|---|---|---|
| 91 | 0.3640E 03 | 0.7047E 00 | 0.1383E 00 | 0.7183E 00 | 0.6840E-01 |

| NNP | DEPTH,FT | U,PSI | SET,IN, | ULTSET,IN |
|---|---|---|---|---|
| 23 | 0.6 | 0.2650E-02 | 0.1404E 00 | 0.2898E 00 |
| 24 | 1.2 | 0.1395E-01 | 0.3634E 00 | 0.6773E 00 |
| 25 | 1.8 | 0.3406E-01 | 0.6588E 00 | 0.1164E 01 |
| 26 | 2.4 | 0.6022E-01 | 0.1020E 01 | 0.1747E 01 |
| 27 | 3.0 | 0.8774E-01 | 0.1441E 01 | 0.2422E 01 |
| 28 | 3.6 | 0.1110E 00 | 0.1921E 01 | 0.3081E 01 |
| 29 | 5.6 | 0.3482E 00 | 0.1949E 01 | 0.3128E 01 |
| 30 | 7.6 | 0.4527E 00 | 0.1960E 01 | 0.3214E 01 |

| | | | | |
|---|---|---|---|---|
| 31 | 9.6 | 0.4947E 00 | 0.1963E 01 | 0.3301E 01 |
| 32 | 11.6 | 0.5094E 00 | 0.1964E 01 | 0.3388E 01 |
| 33 | 13.6 | 0.5137E 00 | 0.1964E 01 | 0.3474E 01 |
| 34 | 15.6 | 0.5145E 00 | 0.1965E 01 | 0.3561E 01 |
| 35 | 17.6 | 0.5135E 00 | 0.1965E 01 | 0.3647E 01 |
| 36 | 19.6 | 0.5084E 00 | 0.1966E 01 | 0.3734E 01 |
| 37 | 21.6 | 0.4910E 00 | 0.1970E 01 | 0.3820E 01 |
| 38 | 23.6 | 0.4385E 00 | 0.1983E 01 | 0.3907E 01 |
| 39 | 25.6 | 0.3955E 00 | 0.1986E 01 | 0.3919E 01 |
| 40 | 27.6 | 0.3521E 00 | 0.1990E 01 | 0.3932E 01 |
| 41 | 29.6 | 0.3086E 00 | 0.1995E 01 | 0.3944E 01 |
| 42 | 31.6 | 0.2648E 00 | 0.2001E 01 | 0.3956E 01 |
| 43 | 33.6 | 0.2208E 00 | 0.2008E 01 | 0.3969E 01 |
| 44 | 35.6 | 0.1767E 00 | 0.2016E 01 | 0.3981E 01 |
| 45 | 37.6 | 0.1326E 00 | 0.2025E 01 | 0.3994E 01 |
| 46 | 39.6 | 0.8837E-01 | 0.2035E 01 | 0.4006E 01 |
| 47 | 41.6 | 0.4416E-01 | 0.2047E 01 | 0.4018E 01 |
| 48 | 43.6 | 0. | 0.2059E 01 | 0.4031E 01 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN. | SET FS,IN. |
|---|---|---|---|---|---|
| 150 | 0.6000E 03 | 0.6317E 00 | 0.1393E 00 | 0.1921E 01 | 0.1378E 00 |

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 23 | 0.6 | 0.1315E-02 | 0.1427E 00 | 0.2898E 00 |
| 24 | 1.2 | 0.6974E-02 | 0.3755E 00 | 0.6773E 00 |
| 25 | 1.8 | 0.1717E-01 | 0.6926E 00 | 0.1104E 01 |
| 26 | 2.4 | 0.3062E-01 | 0.1089E 01 | 0.1747E 01 |
| 27 | 3.0 | 0.4496E-01 | 0.1559E 01 | 0.2422E 01 |
| 28 | 3.6 | 0.5722E-01 | 0.2098E 01 | 0.3041E 01 |
| 29 | 5.6 | 0.3049E 00 | 0.2133E 01 | 0.3128E 01 |
| 30 | 7.6 | 0.4301E 00 | 0.2147E 01 | 0.3214E 01 |
| 31 | 9.6 | 0.4845E 00 | 0.2153E 01 | 0.3301E 01 |
| 32 | 11.6 | 0.5053E 00 | 0.2154E 01 | 0.3388E 01 |
| 33 | 13.6 | 0.5122E 00 | 0.2155E 01 | 0.3474E 01 |
| 34 | 15.6 | 0.5137E 00 | 0.2155E 01 | 0.3561E 01 |
| 35 | 17.6 | 0.5118E 00 | 0.2156E 01 | 0.3647E 01 |
| 36 | 19.6 | 0.5035E 00 | 0.2158E 01 | 0.3734E 01 |
| 37 | 21.6 | 0.4784E 00 | 0.2164E 01 | 0.3820E 01 |
| 38 | 23.6 | 0.4131E 00 | 0.2181E 01 | 0.3907E 01 |
| 39 | 25.6 | 0.3726E 00 | 0.2184E 01 | 0.3919E 01 |
| 40 | 27.6 | 0.3317E 00 | 0.2189E 01 | 0.3932E 01 |
| 41 | 29.6 | 0.2907E 00 | 0.2194E 01 | 0.3944E 01 |
| 42 | 31.6 | 0.2494E 00 | 0.2201E 01 | 0.3956E 01 |
| 43 | 33.6 | 0.2080E 00 | 0.2208E 01 | 0.3969E 01 |
| 44 | 35.6 | 0.1665E 00 | 0.2216E 01 | 0.3981E 01 |
| 45 | 37.6 | 0.1249E 00 | 0.2226E 01 | 0.3994E 01 |
| 46 | 39.6 | 0.8325E-01 | 0.2236E 01 | 0.4006E 01 |
| 47 | 41.6 | 0.4160E-01 | 0.2247E 01 | 0.4018E 01 |
| 48 | 43.6 | 0. | 0.2260E 01 | 0.4031E 01 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN. | SET FS,IN. |
|---|---|---|---|---|---|

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182 0.7280E 03 0.6898E 00 0.1637E 00 0.2098E 01 0.1619E 00

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 20 | 0.6 | 0.2436E-02 | 0.1408E 00 | 0.2898E 00 |
| 21 | 1.2 | 0.1309E-01 | 0.3649E 00 | 0.6773E 00 |
| 22 | 1.8 | 0.3287E-01 | 0.6618E 00 | 0.1164E 01 |
| 23 | 2.4 | 0.6052E-01 | 0.1022E 01 | 0.1747E 01 |
| 24 | 3.0 | 0.9337E-01 | 0.1437E 01 | 0.2422E 01 |
| 25 | 3.6 | 0.1281E 00 | 0.1902E 01 | 0.3186E 01 |
| 26 | 4.2 | 0.1612E 00 | 0.2420E 01 | 0.4037E 01 |
| 27 | 4.8 | 0.1896E 00 | 0.2996E 01 | 0.4971E 01 |
| 28 | 5.4 | 0.2106E 00 | 0.3628E 01 | 0.5841E 01 |
| 29 | 7.4 | 0.4824E 00 | 0.3677E 01 | 0.5971E 01 |
| 30 | 9.4 | 0.6359E 00 | 0.3700E 01 | 0.6101E 01 |
| 31 | 11.4 | 0.7145E 00 | 0.3710E 01 | 0.6231E 01 |
| 32 | 13.4 | 0.7502E 00 | 0.3714E 01 | 0.6361E 01 |
| 33 | 15.4 | 0.7641E 00 | 0.3715E 01 | 0.6490E 01 |
| 34 | 17.4 | 0.7674E 00 | 0.3716E 01 | 0.6620E 01 |
| 35 | 19.4 | 0.7629E 00 | 0.3718E 01 | 0.6750E 01 |
| 36 | 21.4 | 0.7459E 00 | 0.3722E 01 | 0.6880E 01 |
| 37 | 23.4 | 0.7016E 00 | 0.3734E 01 | 0.7010E 01 |
| 38 | 25.4 | 0.5988E 00 | 0.3764E 01 | 0.7140E 01 |
| 39 | 27.4 | 0.5400E 00 | 0.3769E 01 | 0.7158E 01 |
| 40 | 29.4 | 0.4808E 00 | 0.3776E 01 | 0.7177E 01 |
| 41 | 31.4 | 0.4213E 00 | 0.3785E 01 | 0.7195E 01 |
| 42 | 33.4 | 0.3615E 00 | 0.3794E 01 | 0.7214E 01 |
| 43 | 35.4 | 0.3015E 00 | 0.3806E 01 | 0.7232E 01 |
| 44 | 37.4 | 0.2413E 00 | 0.3819E 01 | 0.7251E 01 |
| 45 | 39.4 | 0.1810E 00 | 0.3833E 01 | 0.7269E 01 |
| 46 | 41.4 | 0.1206E 00 | 0.3848E 01 | 0.7288E 01 |
| 47 | 43.4 | 0.6029E-01 | 0.3865E 01 | 0.7307E 01 |
| 48 | 45.4 | 0. | 0.3884E 01 | 0.7325E 01 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN, | SET FS,IN, |
|---|---|---|---|---|---|
| 250 | 0.1000E 04 | 0.6212E 00 | 0.1723E 00 | 0.3628E 01 | 0.2557E 00 |

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 20 | 0.6 | 0.1729E-02 | 0.1420E 00 | 0.2898E 00 |
| 21 | 1.2 | 0.9395E-02 | 0.3713E 00 | 0.6773E 00 |
| 22 | 1.8 | 0.2393E-01 | 0.6797E 00 | 0.1164E 01 |
| 23 | 2.4 | 0.4479E-01 | 0.1059E 01 | 0.1747E 01 |
| 24 | 3.0 | 0.7036E-01 | 0.1500E 01 | 0.2422E 01 |
| 25 | 3.6 | 0.9832E-01 | 0.1997E 01 | 0.3186E 01 |
| 26 | 4.2 | 0.1259E 00 | 0.2553E 01 | 0.4037E 01 |
| 27 | 4.8 | 0.1502E 00 | 0.3168E 01 | 0.4971E 01 |
| 28 | 5.4 | 0.1684E 00 | 0.3842E 01 | 0.5841E 01 |
| 29 | 7.4 | 0.4535E 00 | 0.3895E 01 | 0.5971E 01 |
| 30 | 9.4 | 0.6175E 00 | 0.3921E 01 | 0.6101E 01 |
| 31 | 11.4 | 0.7038E 00 | 0.3933E 01 | 0.6231E 01 |
| 32 | 13.4 | 0.7446E 00 | 0.3938E 01 | 0.6361E 01 |

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|---|---|---|---|---|
| 33 | 15.4 | 0.7613E 00 | 0.3940E 01 | 0.6490E 01 |
| 34 | 17.4 | 0.7653E 00 | 0.3941E 01 | 0.6620E 01 |
| 35 | 19.4 | 0.7597E 00 | 0.3943E 01 | 0.6750E 01 |
| 36 | 21.4 | 0.7390E 00 | 0.3949E 01 | 0.6880E 01 |
| 37 | 23.4 | 0.6873E 00 | 0.3963E 01 | 0.7010E 01 |
| 38 | 25.4 | 0.5741E 00 | 0.3997E 01 | 0.7140E 01 |
| 39 | 27.4 | 0.5177E 00 | 0.4003E 01 | 0.7158E 01 |
| 40 | 29.4 | 0.4609E 00 | 0.4010E 01 | 0.7177E 01 |
| 41 | 31.4 | 0.4039E 00 | 0.4019E 01 | 0.7195E 01 |
| 42 | 33.4 | 0.3466E 00 | 0.4029E 01 | 0.7214E 01 |
| 43 | 35.4 | 0.2890E 00 | 0.4041E 01 | 0.7232E 01 |
| 44 | 37.4 | 0.2313E 00 | 0.4054E 01 | 0.7251E 01 |
| 45 | 39.4 | 0.1735E 00 | 0.4068E 01 | 0.7269E 01 |
| 46 | 41.4 | 0.1157E 00 | 0.4084E 01 | 0.7288E 01 |
| 47 | 43.4 | 0.5780E-01 | 0.4101E 01 | 0.7307E 01 |
| 48 | 45.4 | 0. | 0.4120E 01 | 0.7325E 01 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN, | SET FS,IN, |
|---|---|---|---|---|---|
| 273 | 0.1092E 04 | 0.6577E 00 | 0.1874E 00 | 0.3842E 01 | 0.2781E 00 |

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 17 | 0.6 | 0.3142E-02 | 0.1396E 00 | 0.2898E 00 |
| 18 | 1.2 | 0.1678E-01 | 0.3585E 00 | 0.6773E 00 |
| 19 | 1.8 | 0.4192E-01 | 0.6438E 00 | 0.1164E 01 |
| 20 | 2.4 | 0.7676E-01 | 0.9843E 00 | 0.1747E 01 |
| 21 | 3.0 | 0.1180E 00 | 0.1371E 01 | 0.2422E 01 |
| 22 | 3.6 | 0.1620E 00 | 0.1798E 01 | 0.3186E 01 |
| 23 | 4.2 | 0.2053E 00 | 0.2269E 01 | 0.4037E 01 |
| 24 | 4.8 | 0.2455E 00 | 0.2785E 01 | 0.4971E 01 |
| 25 | 5.4 | 0.2809E 00 | 0.3349E 01 | 0.5986E 01 |
| 26 | 6.0 | 0.3104E 00 | 0.3968E 01 | 0.7081E 01 |
| 27 | 6.6 | 0.3334E 00 | 0.4648E 01 | 0.8253E 01 |
| 28 | 7.2 | 0.3494E 00 | 0.5387E 01 | 0.9356E 01 |
| 29 | 9.2 | 0.6430E 00 | 0.5453E 01 | 0.9529E 01 |
| 30 | 11.2 | 0.8277E 00 | 0.5487E 01 | 0.9702E 01 |
| 31 | 13.2 | 0.9325E 00 | 0.5503E 01 | 0.9875E 01 |
| 32 | 15.2 | 0.9861E 00 | 0.5511E 01 | 0.1005E 02 |
| 33 | 17.2 | 0.1010E 01 | 0.5514E 01 | 0.1022E 02 |
| 34 | 19.2 | 0.1016E 01 | 0.5517E 01 | 0.1039E 02 |
| 35 | 21.2 | 0.1007E 01 | 0.5521E 01 | 0.1057E 02 |
| 36 | 23.2 | 0.9757E 00 | 0.5530E 01 | 0.1074E 02 |
| 37 | 25.2 | 0.9046E 00 | 0.5551E 01 | 0.1091E 02 |
| 38 | 27.2 | 0.7568E 00 | 0.5597E 01 | 0.1109E 02 |
| 39 | 29.2 | 0.6825E 00 | 0.5605E 01 | 0.1111E 02 |
| 40 | 31.2 | 0.6077E 00 | 0.5615E 01 | 0.1114E 02 |
| 41 | 33.2 | 0.5324E 00 | 0.5627E 01 | 0.1116E 02 |
| 42 | 35.2 | 0.4569E 00 | 0.5641E 01 | 0.1119E 02 |
| 43 | 37.2 | 0.3810E 00 | 0.5657E 01 | 0.1121E 02 |
| 44 | 39.2 | 0.3050E 00 | 0.5674E 01 | 0.1124E 02 |
| 45 | 41.2 | 0.2287E 00 | 0.5693E 01 | 0.1126E 02 |
| 46 | 43.2 | 0.1525E 00 | 0.5714E 01 | 0.1128E 02 |

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|---|---|---|---|---|
| 47 | 45.2 | 0.7620E-01 | 0.5737E 01 | 0.1131E 02 |
| 48 | 47.2 | 0. | 0.5762E 01 | 0.1133E 02 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN. | SET FS,IN. |
|---|---|---|---|---|---|
| 330 | 0.1320E 04 | 0.5759E 00 | 0.1893E 00 | 0.5387E 01 | 0.3745E 00 |

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 17 | 0.6 | 0.1926E-02 | 0.1417E 00 | 0.2898E 00 |
| 18 | 1.2 | 0.1053E-01 | 0.3694E 00 | 0.6773E 00 |
| 19 | 1.8 | 0.2705E-01 | 0.6738E 00 | 0.1164E 01 |
| 20 | 2.4 | 0.5123E-01 | 0.1045E 01 | 0.1747E 01 |
| 21 | 3.0 | 0.8180E-01 | 0.1473E 01 | 0.2422E 01 |
| 22 | 3.6 | 0.1168E 00 | 0.1949E 01 | 0.3186E 01 |
| 23 | 4.2 | 0.1540E 00 | 0.2473E 01 | 0.4037E 01 |
| 24 | 4.8 | 0.1910E 00 | 0.3044E 01 | 0.4971E 01 |
| 25 | 5.4 | 0.2257E 00 | 0.3662E 01 | 0.5986E 01 |
| 26 | 6.0 | 0.2562E 00 | 0.4334E 01 | 0.7081E 01 |
| 27 | 6.6 | 0.2809E 00 | 0.5062E 01 | 0.8253E 01 |
| 28 | 7.2 | 0.2983E 00 | 0.5848E 01 | 0.9356E 01 |
| 29 | 9.2 | 0.6041E 00 | 0.5919E 01 | 0.9529E 01 |
| 30 | 11.2 | 0.7993E 00 | 0.5958E 01 | 0.9702E 01 |
| 31 | 13.2 | 0.9139E 00 | 0.5978E 01 | 0.9875E 01 |
| 32 | 15.2 | 0.9749E 00 | 0.5987E 01 | 0.1005E 02 |
| 33 | 17.2 | 0.1003E 01 | 0.5992E 01 | 0.1022E 02 |
| 34 | 19.2 | 0.1010E 01 | 0.5995E 01 | 0.1039E 02 |
| 35 | 21.2 | 0.9981E 00 | 0.6001E 01 | 0.1057E 02 |
| 36 | 23.2 | 0.9605E 00 | 0.6012E 01 | 0.1074E 02 |
| 37 | 25.2 | 0.8767E 00 | 0.6038E 01 | 0.1091E 02 |
| 38 | 27.2 | 0.7116E 00 | 0.6092E 01 | 0.1109E 02 |
| 39 | 29.2 | 0.6417E 00 | 0.6101E 01 | 0.1111E 02 |
| 40 | 31.2 | 0.5713E 00 | 0.6112E 01 | 0.1114E 02 |
| 41 | 33.2 | 0.5006E 00 | 0.6125E 01 | 0.1116E 02 |
| 42 | 35.2 | 0.4295E 00 | 0.6139E 01 | 0.1119E 02 |
| 43 | 37.2 | 0.3582E 00 | 0.6155E 01 | 0.1121E 02 |
| 44 | 39.2 | 0.2867E 00 | 0.6173E 01 | 0.1124E 02 |
| 45 | 41.2 | 0.2151E 00 | 0.6193E 01 | 0.1126E 02 |
| 46 | 43.2 | 0.1434E 00 | 0.6214E 01 | 0.1128E 02 |
| 47 | 45.2 | 0.7164E-01 | 0.6237E 01 | 0.1131E 02 |
| 48 | 47.2 | 0. | 0.6262E 01 | 0.1133E 02 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN. | SET FS,IN. |
|---|---|---|---|---|---|
| 364 | 0.1456E 04 | 0.6250E 00 | 0.2093E 00 | 0.5848E 01 | 0.4142E 00 |

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 14 | 0.6 | 0.5391E-02 | 0.1358E 00 | 0.2898E 00 |
| 15 | 1.2 | 0.2748E-01 | 0.3396E 00 | 0.6773E 00 |
| 16 | 1.8 | 0.6515E-01 | 0.5950E 00 | 0.1164E 01 |
| 17 | 2.4 | 0.1127E 00 | 0.8924E 00 | 0.1747E 01 |
| 18 | 3.0 | 0.1637E 00 | 0.1227E 01 | 0.2422E 01 |
| 19 | 3.6 | 0.2135E 00 | 0.1597E 01 | 0.3186E 01 |

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|---|---|---|---|---|
| 20 | 4.2 | 0.2600E 00 | 0.2010E 01 | 0.4037E 01 |
| 21 | 4.8 | 0.3026E 00 | 0.2467E 01 | 0.4971E 01 |
| 22 | 5.4 | 0.3419E 00 | 0.2969E 01 | 0.5986E 01 |
| 23 | 6.0 | 0.3783E 00 | 0.3520E 01 | 0.7081E 01 |
| 24 | 6.6 | 0.4120E 00 | 0.4121E 01 | 0.8253E 01 |
| 25 | 7.2 | 0.4425E 00 | 0.4773E 01 | 0.9501E 01 |
| 26 | 7.8 | 0.4691E 00 | 0.5481E 01 | 0.1082E 02 |
| 27 | 8.4 | 0.4907E 00 | 0.6248E 01 | 0.1222E 02 |
| 28 | 9.0 | 0.5059E 00 | 0.7073E 01 | 0.1354E 02 |
| 29 | 11.0 | 0.8203E 00 | 0.7152E 01 | 0.1375E 02 |
| 30 | 13.0 | 0.1026E 01 | 0.7196E 01 | 0.1397E 02 |
| 31 | 15.0 | 0.1151E 01 | 0.7219E 01 | 0.1419E 02 |
| 32 | 17.0 | 0.1219E 01 | 0.7230E 01 | 0.1440E 02 |
| 33 | 19.0 | 0.1252E 01 | 0.7237E 01 | 0.1462E 02 |
| 34 | 21.0 | 0.1260E 01 | 0.7241E 01 | 0.1483E 02 |
| 35 | 23.0 | 0.1245E 01 | 0.7249E 01 | 0.1505E 02 |
| 36 | 25.0 | 0.1200E 01 | 0.7263E 01 | 0.1527E 02 |
| 37 | 27.0 | 0.1103E 01 | 0.7294E 01 | 0.1548E 02 |
| 38 | 29.0 | 0.9159E 00 | 0.7357E 01 | 0.1570E 02 |
| 39 | 31.0 | 0.8261E 00 | 0.7368E 01 | 0.1573E 02 |
| 40 | 33.0 | 0.7357E 00 | 0.7381E 01 | 0.1576E 02 |
| 41 | 35.0 | 0.6448E 00 | 0.7397E 01 | 0.1579E 02 |
| 42 | 37.0 | 0.5533E 00 | 0.7414E 01 | 0.1582E 02 |
| 43 | 39.0 | 0.4615E 00 | 0.7434E 01 | 0.1585E 02 |
| 44 | 41.0 | 0.3694E 00 | 0.7456E 01 | 0.1589E 02 |
| 45 | 43.0 | 0.2771E 00 | 0.7481E 01 | 0.1592E 02 |
| 46 | 45.0 | 0.1847E 00 | 0.7507E 01 | 0.1595E 02 |
| 47 | 47.0 | 0.9230E-01 | 0.7536E 01 | 0.1598E 02 |
| 48 | 49.0 | 0. | 0.7567E 01 | 0.1601E 02 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN. | SET FS,IN. |
|---|---|---|---|---|---|
| 400 | 0.1600E 04 | 0.5225E 00 | 0.1995E 00 | 0.7073E 01 | 0.4933E 00 |

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 14 | 0.6 | 0.2033E-02 | 0.1415E 00 | 0.2898E 00 |
| 15 | 1.2 | 0.1115E-01 | 0.3683E 00 | 0.6773E 00 |
| 16 | 1.8 | 0.2876E-01 | 0.6705E 00 | 0.1164E 01 |
| 17 | 2.4 | 0.5478E-01 | 0.1037E 01 | 0.1747E 01 |
| 18 | 3.0 | 0.8814E-01 | 0.1458E 01 | 0.2422E 01 |
| 19 | 3.6 | 0.1271E 00 | 0.1922E 01 | 0.3186E 01 |
| 20 | 4.2 | 0.1696E 00 | 0.2430E 01 | 0.4037E 01 |
| 21 | 4.8 | 0.2136E 00 | 0.2976E 01 | 0.4971E 01 |
| 22 | 5.4 | 0.2572E 00 | 0.3561E 01 | 0.5986E 01 |
| 23 | 6.0 | 0.2987E 00 | 0.4188E 01 | 0.7081E 01 |
| 24 | 6.6 | 0.3368E 00 | 0.4859E 01 | 0.8253E 01 |
| 25 | 7.2 | 0.3705E 00 | 0.5575E 01 | 0.9501E 01 |
| 26 | 7.8 | 0.3989E 00 | 0.6345E 01 | 0.1082E 02 |
| 27 | 8.4 | 0.4212E 00 | 0.7172E 01 | 0.1222E 02 |
| 28 | 9.0 | 0.4368E 00 | 0.8056E 01 | 0.1354E 02 |
| 29 | 11.0 | 0.7599E 00 | 0.8145E 01 | 0.1375E 02 |
| 30 | 13.0 | 0.9795E 00 | 0.8197E 01 | 0.1397E 02 |

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|---|---|---|---|---|
| 31 | 15.0 | 0.1118E 01 | 0.8225E 01 | 0.1419E 02 |
| 32 | 17.0 | 0.1197E 01 | 0.8241E 01 | 0.1440E 02 |
| 33 | 19.0 | 0.1236E 01 | 0.8249E 01 | 0.1462E 02 |
| 34 | 21.0 | 0.1245E 01 | 0.8257E 01 | 0.1483E 02 |
| 35 | 23.0 | 0.1226E 01 | 0.8267E 01 | 0.1505E 02 |
| 36 | 25.0 | 0.1168E 01 | 0.8287E 01 | 0.1527E 02 |
| 37 | 27.0 | 0.1048E 01 | 0.8328E 01 | 0.1548E 02 |
| 38 | 29.0 | 0.8297E 00 | 0.8405E 01 | 0.1570E 02 |
| 39 | 31.0 | 0.7482E 00 | 0.8418E 01 | 0.1573E 02 |
| 40 | 33.0 | 0.6662E 00 | 0.8433E 01 | 0.1576E 02 |
| 41 | 35.0 | 0.5837E 00 | 0.8449E 01 | 0.1579E 02 |
| 42 | 37.0 | 0.5008E 00 | 0.8468E 01 | 0.1582E 02 |
| 43 | 39.0 | 0.4177E 00 | 0.8489E 01 | 0.1585E 02 |
| 44 | 41.0 | 0.3343E 00 | 0.8512E 01 | 0.1589E 02 |
| 45 | 43.0 | 0.2507E 00 | 0.8537E 01 | 0.1592E 02 |
| 46 | 45.0 | 0.1671E 00 | 0.8564E 01 | 0.1595E 02 |
| 47 | 47.0 | 0.8353E-01 | 0.8593E 01 | 0.1598E 02 |
| 48 | 49.0 | 0. | 0.8624E 01 | 0.1601E 02 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN, | SET FS,IN, |
|---|---|---|---|---|---|
| 455 | 0.1820E 04 | 0.5952E 00 | 0.2295E 00 | 0.8056E 01 | 0.5675E 00 |

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 11 | 0.6 | 0.4178E-02 | 0.1379E 00 | 0.2898E 00 |
| 12 | 1.2 | 0.2195E-01 | 0.3495E 00 | 0.6773E 00 |
| 13 | 1.8 | 0.5379E-01 | 0.6195E 00 | 0.1164E 01 |
| 14 | 2.4 | 0.9655E-01 | 0.9362E 00 | 0.1747E 01 |
| 15 | 3.0 | 0.1457E 00 | 0.1291E 01 | 0.2422E 01 |
| 16 | 3.6 | 0.1970E 00 | 0.1679E 01 | 0.3186E 01 |
| 17 | 4.2 | 0.2477E 00 | 0.2104E 01 | 0.4037E 01 |
| 18 | 4.8 | 0.2964E 00 | 0.2567E 01 | 0.4971E 01 |
| 19 | 5.4 | 0.3428E 00 | 0.3067E 01 | 0.5986E 01 |
| 20 | 6.0 | 0.3871E 00 | 0.3607E 01 | 0.7081E 01 |
| 21 | 6.6 | 0.4295E 00 | 0.4189E 01 | 0.8253E 01 |
| 22 | 7.2 | 0.4700E 00 | 0.4811E 01 | 0.9501E 01 |
| 23 | 7.8 | 0.5082E 00 | 0.5478E 01 | 0.1082E 02 |
| 24 | 8.4 | 0.5436E 00 | 0.6190E 01 | 0.1222E 02 |
| 25 | 9.0 | 0.5752E 00 | 0.6950E 01 | 0.1368E 02 |
| 26 | 9.6 | 0.6022E 00 | 0.7763E 01 | 0.1522E 02 |
| 27 | 10.2 | 0.6237E 00 | 0.8633E 01 | 0.1682E 02 |
| 28 | 10.8 | 0.6387E 00 | 0.9560E 01 | 0.1835E 02 |
| 29 | 12.8 | 0.9694E 00 | 0.9657E 01 | 0.1860E 02 |
| 30 | 14.8 | 0.1199E 01 | 0.9715E 01 | 0.1886E 02 |
| 31 | 16.8 | 0.1347E 01 | 0.9748E 01 | 0.1912E 02 |
| 32 | 18.8 | 0.1435E 01 | 0.9767E 01 | 0.1938E 02 |
| 33 | 20.8 | 0.1479E 01 | 0.9778E 01 | 0.1964E 02 |
| 34 | 22.8 | 0.1488E 01 | 0.9788E 01 | 0.1990E 02 |
| 35 | 24.8 | 0.1464E 01 | 0.9802E 01 | 0.2016E 02 |
| 36 | 26.8 | 0.1395E 01 | 0.9827E 01 | 0.2042E 02 |
| 37 | 28.8 | 0.1258E 01 | 0.9875E 01 | 0.2068E 02 |
| 38 | 30.8 | 0.1011E 01 | 0.9965E 01 | 0.2094E 02 |

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|---|---|---|---|---|
| 39 | 32.8 | 0.9116E 00 | 0.9980E 01 | 0.2098E 02 |
| 40 | 34.8 | 0.8116E 00 | 0.9998E 01 | 0.2102E 02 |
| 41 | 36.8 | 0.7112E 00 | 0.1002E 02 | 0.2105E 02 |
| 42 | 38.8 | 0.6102E 00 | 0.1004E 02 | 0.2109E 02 |
| 43 | 40.8 | 0.5089E 00 | 0.1007E 02 | 0.2113E 02 |
| 44 | 42.8 | 0.4073E 00 | 0.1009E 02 | 0.2116E 02 |
| 45 | 44.8 | 0.3055E 00 | 0.1012E 02 | 0.2120E 02 |
| 46 | 46.8 | 0.2037E 00 | 0.1015E 02 | 0.2124E 02 |
| 47 | 48.8 | 0.1018E 00 | 0.1019E 02 | 0.2128E 02 |
| 48 | 50.8 | 0. | 0.1023E 02 | 0.2131E 02 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN, | SET FS,IN, |
|---|---|---|---|---|---|
| 500 | 0.2000E 04 | 0.5211E 00 | 0.2246E 00 | 0.9560E 01 | 0.6665E 00 |

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 11 | 0.6 | 0.2093E-02 | 0.1414E 00 | 0.2898E 00 |
| 12 | 1.2 | 0.1150E-01 | 0.3678E 00 | 0.6773E 00 |
| 13 | 1.8 | 0.2971E-01 | 0.6687E 00 | 0.1164E 01 |
| 14 | 2.4 | 0.5677E-01 | 0.1033E 01 | 0.1747E 01 |
| 15 | 3.0 | 0.9170E-01 | 0.1449E 01 | 0.2422E 01 |
| 16 | 3.6 | 0.1329E 00 | 0.1907E 01 | 0.3186E 01 |
| 17 | 4.2 | 0.1785E 00 | 0.2405E 01 | 0.4037E 01 |
| 18 | 4.8 | 0.2266E 00 | 0.2938E 01 | 0.4971E 01 |
| 19 | 5.4 | 0.2755E 00 | 0.3503E 01 | 0.5986E 01 |
| 20 | 6.0 | 0.3237E 00 | 0.4104E 01 | 0.7081E 01 |
| 21 | 6.6 | 0.3701E 00 | 0.4741E 01 | 0.8253E 01 |
| 22 | 7.2 | 0.4139E 00 | 0.5414E 01 | 0.9501E 01 |
| 23 | 7.8 | 0.4543E 00 | 0.6128E 01 | 0.1082E 02 |
| 24 | 8.4 | 0.4907E 00 | 0.6886E 01 | 0.1222E 02 |
| 25 | 9.0 | 0.5226E 00 | 0.7690E 01 | 0.1368E 02 |
| 26 | 9.6 | 0.5493E 00 | 0.8547E 01 | 0.1522E 02 |
| 27 | 10.2 | 0.5703E 00 | 0.9461E 01 | 0.1682E 02 |
| 28 | 10.8 | 0.5850E 00 | 0.1043E 02 | 0.1835E 02 |
| 29 | 12.8 | 0.9216E 00 | 0.1054E 02 | 0.1860E 02 |
| 30 | 14.8 | 0.1160E 01 | 0.1060E 02 | 0.1886E 02 |
| 31 | 16.8 | 0.1318E 01 | 0.1064E 02 | 0.1912E 02 |
| 32 | 18.8 | 0.1413E 01 | 0.1066E 02 | 0.1938E 02 |
| 33 | 20.8 | 0.1461E 01 | 0.1067E 02 | 0.1964E 02 |
| 34 | 22.8 | 0.1471E 01 | 0.1069E 02 | 0.1990E 02 |
| 35 | 24.8 | 0.1441E 01 | 0.1070E 02 | 0.2016E 02 |
| 36 | 26.8 | 0.1360E 01 | 0.1074E 02 | 0.2042E 02 |
| 37 | 28.8 | 0.1204E 01 | 0.1079E 02 | 0.2068E 02 |
| 38 | 30.8 | 0.9317E 00 | 0.1090E 02 | 0.2094E 02 |
| 39 | 32.8 | 0.8401E 00 | 0.1091E 02 | 0.2098E 02 |
| 40 | 34.8 | 0.7480E 00 | 0.1093E 02 | 0.2102E 02 |
| 41 | 36.8 | 0.6554E 00 | 0.1095E 02 | 0.2105E 02 |
| 42 | 38.8 | 0.5623E 00 | 0.1098E 02 | 0.2109E 02 |
| 43 | 40.8 | 0.4689E 00 | 0.1100E 02 | 0.2113E 02 |
| 44 | 42.8 | 0.3753E 00 | 0.1103E 02 | 0.2116E 02 |
| 45 | 44.8 | 0.2815E 00 | 0.1106E 02 | 0.2120E 02 |
| 46 | 46.8 | 0.1877E 00 | 0.1109E 02 | 0.2124E 02 |

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| 47 | 48.8 | 0.9379E-01 | 0.1113E 02 | 0.2128E 02 |
| 48 | 50.8 | 0. | 0.1117E 02 | 0.2131E 02 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN, | SET FS,IN, |
|---|---|---|---|---|---|
| 546 | 0.2184E 04 | 0.5686E 00 | 0.2481E 00 | 0.1043E 02 | 0.7362E 00 |

| NNP | DEPTH,FT | U,PSI | SET,IN, | ULTSET,IN |
|---|---|---|---|---|
| 8 | 0.6 | 0.3461E-02 | 0.1391E 00 | 0.2898E 00 |
| 9 | 1.2 | 0.1850E-01 | 0.3556E 00 | 0.6773E 00 |
| 10 | 1.8 | 0.4627E-01 | 0.6352E 00 | 0.1164E 01 |
| 11 | 2.4 | 0.8502E-01 | 0.9657E 00 | 0.1747E 01 |
| 12 | 3.0 | 0.1315E 00 | 0.1336E 01 | 0.2422E 01 |
| 13 | 3.6 | 0.1824E 00 | 0.1741E 01 | 0.3186E 01 |
| 14 | 4.2 | 0.2348E 00 | 0.2179E 01 | 0.4037E 01 |
| 15 | 4.8 | 0.2870E 00 | 0.2650E 01 | 0.4971E 01 |
| 16 | 5.4 | 0.3381E 00 | 0.3154E 01 | 0.5986E 01 |
| 17 | 6.0 | 0.3878E 00 | 0.3693E 01 | 0.7081E 01 |
| 18 | 6.6 | 0.4363E 00 | 0.4267E 01 | 0.8253E 01 |
| 19 | 7.2 | 0.4834E 00 | 0.4874E 01 | 0.9501E 01 |
| 20 | 7.8 | 0.5292E 00 | 0.5519E 01 | 0.1082E 02 |
| 21 | 8.4 | 0.5733E 00 | 0.6201E 01 | 0.1222E 02 |
| 22 | 9.0 | 0.6152E 00 | 0.6919E 01 | 0.1368E 02 |
| 23 | 9.6 | 0.6543E 00 | 0.7680E 01 | 0.1522E 02 |
| 24 | 10.2 | 0.6898E 00 | 0.8484E 01 | 0.1682E 02 |
| 25 | 10.8 | 0.7210E 00 | 0.9333E 01 | 0.1849E 02 |
| 26 | 11.4 | 0.7474E 00 | 0.1024E 02 | 0.2023E 02 |
| 27 | 12.0 | 0.7681E 00 | 0.1119E 02 | 0.2203E 02 |
| 28 | 12.6 | 0.7827E 00 | 0.1221E 02 | 0.2375E 02 |
| 29 | 14.6 | 0.1125E 01 | 0.1232E 02 | 0.2405E 02 |
| 30 | 16.6 | 0.1372E 01 | 0.1239E 02 | 0.2436E 02 |
| 31 | 18.6 | 0.1540E 01 | 0.1244E 02 | 0.2466E 02 |
| 32 | 20.6 | 0.1643E 01 | 0.1247E 02 | 0.2496E 02 |
| 33 | 22.6 | 0.1696E 01 | 0.1248E 02 | 0.2526E 02 |
| 34 | 24.6 | 0.1705E 01 | 0.1250E 02 | 0.2557E 02 |
| 35 | 26.6 | 0.1668E 01 | 0.1252E 02 | 0.2587E 02 |
| 36 | 28.6 | 0.1573E 01 | 0.1256E 02 | 0.2617E 02 |
| 37 | 30.6 | 0.1394E 01 | 0.1263E 02 | 0.2648E 02 |
| 38 | 32.6 | 0.1088E 01 | 0.1275E 02 | 0.2678E 02 |
| 39 | 34.6 | 0.9814E 00 | 0.1277E 02 | 0.2682E 02 |
| 40 | 36.6 | 0.8738E 00 | 0.1279E 02 | 0.2687E 02 |
| 41 | 38.6 | 0.7656E 00 | 0.1282E 02 | 0.2691E 02 |
| 42 | 40.6 | 0.6569E 00 | 0.1284E 02 | 0.2695E 02 |
| 43 | 42.6 | 0.5478E 00 | 0.1287E 02 | 0.2700E 02 |
| 44 | 44.6 | 0.4384E 00 | 0.1291E 02 | 0.2704E 02 |
| 45 | 46.6 | 0.3289E 00 | 0.1294E 02 | 0.2708E 02 |
| 46 | 48.6 | 0.2192E 00 | 0.1298E 02 | 0.2713E 02 |
| 47 | 50.6 | 0.1096E 00 | 0.1302E 02 | 0.2717E 02 |
| 48 | 52.6 | 0. | 0.1307E 02 | 0.2721E 02 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN, | SET FS,IN, |
|---|---|---|---|---|---|
| 600 | 0.2400E 04 | 0.5140E 00 | 0.2476E 00 | 0.1221E 02 | 0.8572E 00 |

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 8 | 0.6 | 0.2128E-02 | 0.1413E 00 | 0.2898E 00 |
| 9 | 1.2 | 0.1170E-01 | 0.3674E 00 | 0.6773E 00 |
| 10 | 1.8 | 0.3027E-01 | 0.6676E 00 | 0.1164E 01 |
| 11 | 2.4 | 0.5794E-01 | 0.1031E 01 | 0.1747E 01 |
| 12 | 3.0 | 0.9380E-01 | 0.1444E 01 | 0.2422E 01 |
| 13 | 3.6 | 0.1364E 00 | 0.1899E 01 | 0.3186E 01 |
| 14 | 4.2 | 0.1838E 00 | 0.2390E 01 | 0.4037E 01 |
| 15 | 4.8 | 0.2344E 00 | 0.2915E 01 | 0.4971E 01 |
| 16 | 5.4 | 0.2865E 00 | 0.3469E 01 | 0.5986E 01 |
| 17 | 6.0 | 0.3388E 00 | 0.4054E 01 | 0.7081E 01 |
| 18 | 6.6 | 0.3903E 00 | 0.4671E 01 | 0.8253E 01 |
| 19 | 7.2 | 0.4404E 00 | 0.5317E 01 | 0.9501E 01 |
| 20 | 7.8 | 0.4884E 00 | 0.5998E 01 | 0.1082E 02 |
| 21 | 8.4 | 0.5340E 00 | 0.6714E 01 | 0.1222E 02 |
| 22 | 9.0 | 0.5766E 00 | 0.7465E 01 | 0.1368E 02 |
| 23 | 9.6 | 0.6158E 00 | 0.8257E 01 | 0.1522E 02 |
| 24 | 10.2 | 0.6511E 00 | 0.9093E 01 | 0.1682E 02 |
| 25 | 10.8 | 0.6820E 00 | 0.9974E 01 | 0.1849E 02 |
| 26 | 11.4 | 0.7079E 00 | 0.1091E 02 | 0.2023E 02 |
| 27 | 12.0 | 0.7283E 00 | 0.1190E 02 | 0.2203E 02 |
| 28 | 12.6 | 0.7427E 00 | 0.1294E 02 | 0.2375E 02 |
| 29 | 14.6 | 0.1089E 01 | 0.1306E 02 | 0.2405E 02 |
| 30 | 16.6 | 0.1342E 01 | 0.1314E 02 | 0.2436E 02 |
| 31 | 18.6 | 0.1515E 01 | 0.1319E 02 | 0.2466E 02 |
| 32 | 20.6 | 0.1623E 01 | 0.1322E 02 | 0.2496E 02 |
| 33 | 22.6 | 0.1678E 01 | 0.1324E 02 | 0.2526E 02 |
| 34 | 24.6 | 0.1686E 01 | 0.1326E 02 | 0.2557E 02 |
| 35 | 26.6 | 0.1645E 01 | 0.1328E 02 | 0.2587E 02 |
| 36 | 28.6 | 0.1540E 01 | 0.1333E 02 | 0.2617E 02 |
| 37 | 30.6 | 0.1345E 01 | 0.1341E 02 | 0.2648E 02 |
| 38 | 32.6 | 0.1020E 01 | 0.1354E 02 | 0.2678E 02 |
| 39 | 34.6 | 0.9198E 00 | 0.1356E 02 | 0.2682E 02 |
| 40 | 36.6 | 0.8189E 00 | 0.1358E 02 | 0.2687E 02 |
| 41 | 38.6 | 0.7175E 00 | 0.1361E 02 | 0.2691E 02 |
| 42 | 40.6 | 0.6156E 00 | 0.1364E 02 | 0.2695E 02 |
| 43 | 42.6 | 0.5134E 00 | 0.1367E 02 | 0.2700E 02 |
| 44 | 44.6 | 0.4109E 00 | 0.1370E 02 | 0.2704E 02 |
| 45 | 46.6 | 0.3082E 00 | 0.1374E 02 | 0.2708E 02 |
| 46 | 48.6 | 0.2054E 00 | 0.1377E 02 | 0.2713E 02 |
| 47 | 50.6 | 0.1027E 00 | 0.1382E 02 | 0.2717E 02 |
| 48 | 52.6 | 0. | 0.1386E 02 | 0.2721E 02 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN. | SET FS,IN. |
|---|---|---|---|---|---|
| 637 | 0.2548E 04 | 0.5449E 00 | 0.2654E 00 | 0.1294E 02 | 0.9187E 00 |

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 5 | 0.6 | 0.4423E-02 | 0.1374E 00 | 0.2898E 00 |
| 6 | 1.2 | 0.2314E-01 | 0.3474E 00 | 0.6773E 00 |

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| | | | | |
|---|---|---|---|---|
| 7 | 1.8 | 0.5648E-01 | 0.6139E 00 | 0.1164E 01 |
| 8 | 2.4 | 0.1009E 00 | 0.9253E 00 | 0.1747E 01 |
| 9 | 3.0 | 0.1518E 00 | 0.1273E 01 | 0.2422E 01 |
| 10 | 3.6 | 0.2048E 00 | 0.1653E 01 | 0.3186E 01 |
| 11 | 4.2 | 0.2575E 00 | 0.2067E 01 | 0.4037E 01 |
| 12 | 4.8 | 0.3089E 00 | 0.2516E 01 | 0.4971E 01 |
| 13 | 5.4 | 0.3592E 00 | 0.2999E 01 | 0.5986E 01 |
| 14 | 6.0 | 0.4088E 00 | 0.3517E 01 | 0.7081E 01 |
| 15 | 6.6 | 0.4585E 00 | 0.4069E 01 | 0.8253E 01 |
| 16 | 7.2 | 0.5083E 00 | 0.4653E 01 | 0.9501E 01 |
| 17 | 7.8 | 0.5582E 00 | 0.5270E 01 | 0.1082E 02 |
| 18 | 8.4 | 0.6078E 00 | 0.5919E 01 | 0.1222E 02 |
| 19 | 9.0 | 0.6566E 00 | 0.6599E 01 | 0.1368E 02 |
| 20 | 9.6 | 0.7039E 00 | 0.7313E 01 | 0.1522E 02 |
| 21 | 10.2 | 0.7491E 00 | 0.8062E 01 | 0.1682E 02 |
| 22 | 10.8 | 0.7915E 00 | 0.8846E 01 | 0.1849E 02 |
| 23 | 11.4 | 0.8305E 00 | 0.9671E 01 | 0.2023E 02 |
| 24 | 12.0 | 0.8656E 00 | 0.1054E 02 | 0.2203E 02 |
| 25 | 12.6 | 0.8962E 00 | 0.1145E 02 | 0.2389E 02 |
| 26 | 13.2 | 0.9219E 00 | 0.1242E 02 | 0.2582E 02 |
| 27 | 13.8 | 0.9421E 00 | 0.1344E 02 | 0.2781E 02 |
| 28 | 14.4 | 0.9563E 00 | 0.1451E 02 | 0.2972E 02 |
| 29 | 16.4 | 0.1305E 01 | 0.1464E 02 | 0.3007E 02 |
| 30 | 18.4 | 0.1564E 01 | 0.1472E 02 | 0.3041E 02 |
| 31 | 20.4 | 0.1743E 01 | 0.1477E 02 | 0.3076E 02 |
| 32 | 22.4 | 0.1856E 01 | 0.1481E 02 | 0.3111E 02 |
| 33 | 24.4 | 0.1914E 01 | 0.1483E 02 | 0.3145E 02 |
| 34 | 26.4 | 0.1921E 01 | 0.1486E 02 | 0.3180E 02 |
| 35 | 28.4 | 0.1873E 01 | 0.1489E 02 | 0.3215E 02 |
| 36 | 30.4 | 0.1756E 01 | 0.1494E 02 | 0.3249E 02 |
| 37 | 32.4 | 0.1543E 01 | 0.1503E 02 | 0.3284E 02 |
| 38 | 34.4 | 0.1192E 01 | 0.1517E 02 | 0.3318E 02 |
| 39 | 36.4 | 0.1075E 01 | 0.1520E 02 | 0.3323E 02 |
| 40 | 38.4 | 0.9574E 00 | 0.1522E 02 | 0.3328E 02 |
| 41 | 40.4 | 0.8389E 00 | 0.1525E 02 | 0.3333E 02 |
| 42 | 42.4 | 0.7198E 00 | 0.1528E 02 | 0.3338E 02 |
| 43 | 44.4 | 0.6003E 00 | 0.1532E 02 | 0.3343E 02 |
| 44 | 46.4 | 0.4804E 00 | 0.1536E 02 | 0.3348E 02 |
| 45 | 48.4 | 0.3604E 00 | 0.1540E 02 | 0.3353E 02 |
| 46 | 50.4 | 0.2402E 00 | 0.1544E 02 | 0.3358E 02 |
| 47 | 52.4 | 0.1201E 00 | 0.1549E 02 | 0.3363E 02 |
| 48 | 54.4 | 0. | 0.1554E 02 | 0.3368E 02 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN. | SET FS,IN. |
|---|---|---|---|---|---|
| 680 | 0.2720E 04 | 0.4882E 00 | 0.2597E 00 | 0.1451E 02 | 0.1028E 01 |

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 3 | 0.6 | 0.2506E-01 | 0.1026E 00 | 0.2898E 00 |
| 4 | 1.2 | 0.7469E-01 | 0.2397E 00 | 0.6773E 00 |
| 5 | 1.8 | 0.1217E 00 | 0.4250E 00 | 0.1164E 01 |
| 6 | 2.4 | 0.1603E 00 | 0.6662E 00 | 0.1747E 01 |

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|---|---|---|---|---|
| 7 | 3.0 | 0.1936E 00 | 0.9649E 00 | 0.2422E 01 |
| 8 | 3.6 | 0.2267E 00 | 0.1322E 01 | 0.3186E 01 |
| 9 | 4.2 | 0.2635E 00 | 0.1730E 01 | 0.4037E 01 |
| 10 | 4.8 | 0.3053E 00 | 0.2181E 01 | 0.4971E 01 |
| 11 | 5.4 | 0.3519E 00 | 0.2671E 01 | 0.5986E 01 |
| 12 | 6.0 | 0.4024E 00 | 0.3195E 01 | 0.7081E 01 |
| 13 | 6.6 | 0.4554E 00 | 0.3749E 01 | 0.8253E 01 |
| 14 | 7.2 | 0.5098E 00 | 0.4331E 01 | 0.9501E 01 |
| 15 | 7.8 | 0.5644E 00 | 0.4942E 01 | 0.1082E 02 |
| 16 | 8.4 | 0.6186E 00 | 0.5580E 01 | 0.1222E 02 |
| 17 | 9.0 | 0.6718E 00 | 0.6246E 01 | 0.1368E 02 |
| 18 | 9.6 | 0.7235E 00 | 0.6942E 01 | 0.1522E 02 |
| 19 | 10.2 | 0.7733E 00 | 0.7667E 01 | 0.1682E 02 |
| 20 | 10.8 | 0.8209E 00 | 0.8425E 01 | 0.1849E 02 |
| 21 | 11.4 | 0.8659E 00 | 0.9217E 01 | 0.2023E 02 |
| 22 | 12.0 | 0.9078E 00 | 0.1004E 02 | 0.2203E 02 |
| 23 | 12.6 | 0.9463E 00 | 0.1091E 02 | 0.2389E 02 |
| 24 | 13.2 | 0.9808E 00 | 0.1182E 02 | 0.2582E 02 |
| 25 | 13.8 | 0.1011E 01 | 0.1278E 02 | 0.2781E 02 |
| 26 | 14.4 | 0.1036E 01 | 0.1378E 02 | 0.2987E 02 |
| 27 | 15.0 | 0.1056E 01 | 0.1484E 02 | 0.3198E 02 |
| 28 | 15.6 | 0.1070E 01 | 0.1596E 02 | 0.3401E 02 |
| 29 | 17.6 | 0.1423E 01 | 0.1610E 02 | 0.3438E 02 |
| 30 | 19.6 | 0.1688E 01 | 0.1619E 02 | 0.3476E 02 |
| 31 | 21.6 | 0.1874E 01 | 0.1625E 02 | 0.3513E 02 |
| 32 | 23.6 | 0.1993E 01 | 0.1629E 02 | 0.3551E 02 |
| 33 | 25.6 | 0.2053E 01 | 0.1632E 02 | 0.3588E 02 |
| 34 | 27.6 | 0.2057E 01 | 0.1635E 02 | 0.3626E 02 |
| 35 | 29.6 | 0.2001E 01 | 0.1639E 02 | 0.3663E 02 |
| 36 | 31.6 | 0.1867E 01 | 0.1645E 02 | 0.3701E 02 |
| 37 | 33.6 | 0.1630E 01 | 0.1655E 02 | 0.3738E 02 |
| 38 | 35.6 | 0.1250E 01 | 0.1671E 02 | 0.3776E 02 |
| 39 | 37.6 | 0.1141E 01 | 0.1674E 02 | 0.3781E 02 |
| 40 | 39.6 | 0.1029E 01 | 0.1677E 02 | 0.3787E 02 |
| 41 | 41.6 | 0.9151E 00 | 0.1680E 02 | 0.3792E 02 |
| 42 | 43.6 | 0.7994E 00 | 0.1684E 02 | 0.3797E 02 |
| 43 | 45.6 | 0.6708E 00 | 0.1687E 02 | 0.3803E 02 |
| 44 | 47.6 | 0.5391E 00 | 0.1691E 02 | 0.3808E 02 |
| 45 | 49.6 | 0.4047E 00 | 0.1696E 02 | 0.3813E 02 |
| 46 | 51.6 | 0.2693E 00 | 0.1700E 02 | 0.3819E 02 |
| 47 | 53.6 | 0.1341E 00 | 0.1705E 02 | 0.3824E 02 |
| 48 | 55.6 | 0. | 0.1711E 02 | 0.3829E 02 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN, | SET FS,IN, |
|---|---|---|---|---|---|
| 738 | 0.2952E 04 | 0.4693E 00 | 0.2679E 00 | 0.1596E 02 | 0.1148E 01 |

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 2 | 0.6 | 0.2162E-02 | 0.1413E 00 | 0.2898E 00 |
| 3 | 1.2 | 0.1189E-01 | 0.3671E 00 | 0.6773E 00 |
| 4 | 1.8 | 0.3082E-01 | 0.6666E 00 | 0.1164E 01 |
| 5 | 2.4 | 0.5908E-01 | 0.1028E 01 | 0.1747E 01 |

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| | | | | |
|---|---|---|---|---|
| 6 | 3.0 | 0.9587E-01 | 0.1440E 01 | 0.2422E 01 |
| 7 | 3.6 | 0.1398E 00 | 0.1890E 01 | 0.3186E 01 |
| 8 | 4.2 | 0.1891E 00 | 0.2376E 01 | 0.4037E 01 |
| 9 | 4.8 | 0.2421E 00 | 0.2892E 01 | 0.4971E 01 |
| 10 | 5.4 | 0.2975E 00 | 0.3435E 01 | 0.5986E 01 |
| 11 | 6.0 | 0.3540E 00 | 0.4005E 01 | 0.7081E 01 |
| 12 | 6.6 | 0.4109E 00 | 0.4600E 01 | 0.8253E 01 |
| 13 | 7.2 | 0.4677E 00 | 0.5220E 01 | 0.9501E 01 |
| 14 | 7.8 | 0.5238E 00 | 0.5866E 01 | 0.1082E 02 |
| 15 | 8.4 | 0.5792E 00 | 0.6538E 01 | 0.1222E 02 |
| 16 | 9.0 | 0.6335E 00 | 0.7236E 01 | 0.1368E 02 |
| 17 | 9.6 | 0.6865E 00 | 0.7961E 01 | 0.1522E 02 |
| 18 | 10.2 | 0.7379E 00 | 0.8715E 01 | 0.1682E 02 |
| 19 | 10.8 | 0.7874E 00 | 0.9497E 01 | 0.1849E 02 |
| 20 | 11.4 | 0.8347E 00 | 0.1031E 02 | 0.2023E 02 |
| 21 | 12.0 | 0.8792E 00 | 0.1116E 02 | 0.2203E 02 |
| 22 | 12.6 | 0.9206E 00 | 0.1204E 02 | 0.2389E 02 |
| 23 | 13.2 | 0.9585E 00 | 0.1296E 02 | 0.2582E 02 |
| 24 | 13.8 | 0.9924E 00 | 0.1393E 02 | 0.2781E 02 |
| 25 | 14.4 | 0.1022E 01 | 0.1494E 02 | 0.2987E 02 |
| 26 | 15.0 | 0.1047E 01 | 0.1600E 02 | 0.3198E 02 |
| 27 | 15.6 | 0.1066E 01 | 0.1711E 02 | 0.3415E 02 |
| 28 | 16.2 | 0.1080E 01 | 0.1828E 02 | 0.3624E 02 |
| 29 | 18.2 | 0.1436E 01 | 0.1843E 02 | 0.3663E 02 |
| 30 | 20.2 | 0.1708E 01 | 0.1853E 02 | 0.3702E 02 |
| 31 | 22.2 | 0.1902E 01 | 0.1860E 02 | 0.3741E 02 |
| 32 | 24.2 | 0.2027E 01 | 0.1865E 02 | 0.3780E 02 |
| 33 | 26.2 | 0.2089E 01 | 0.1869E 02 | 0.3819E 02 |
| 34 | 28.2 | 0.2088E 01 | 0.1873E 02 | 0.3858E 02 |
| 35 | 30.2 | 0.2018E 01 | 0.1878E 02 | 0.3896E 02 |
| 36 | 32.2 | 0.1861E 01 | 0.1886E 02 | 0.3935E 02 |
| 37 | 34.2 | 0.1590E 01 | 0.1898E 02 | 0.3974E 02 |
| 38 | 36.2 | 0.1164E 01 | 0.1917E 02 | 0.4013E 02 |
| 39 | 38.2 | 0.1050E 01 | 0.1920E 02 | 0.4019E 02 |
| 40 | 40.2 | 0.9347E 00 | 0.1924E 02 | 0.4024E 02 |
| 41 | 42.2 | 0.8189E 00 | 0.1927E 02 | 0.4030E 02 |
| 42 | 44.2 | 0.7026E 00 | 0.1931E 02 | 0.4036E 02 |
| 43 | 46.2 | 0.5860E 00 | 0.1935E 02 | 0.4041E 02 |
| 44 | 48.2 | 0.4690E 00 | 0.1940E 02 | 0.4047E 02 |
| 45 | 50.2 | 0.3518E 00 | 0.1944E 02 | 0.4052E 02 |
| 46 | 52.2 | 0.2345E 00 | 0.1949E 02 | 0.4058E 02 |
| 47 | 54.2 | 0.1172E 00 | 0.1955E 02 | 0.4063E 02 |
| 48 | 56.2 | 0. | 0.1960E 02 | 0.4069E 02 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN, | SET FS,IN, |
|---|---|---|---|---|---|
| 819 | 0.3276E 04 | 0.5045E 00 | 0.2967E 00 | 0.1828E 02 | 0.1321E 01 |

| NNP | DEPTH,FT | U,PSI | SET,IN, | ULTSET,IN |
|---|---|---|---|---|
| 2 | 0.6 | 0.1270E-02 | 0.1428E 00 | 0.2898E 00 |
| 3 | 1.2 | 0.7099E-02 | 0.3754E 00 | 0.6773E 00 |
| 4 | 1.8 | 0.1876E-01 | 0.6904E 00 | 0.1164E 01 |

| | | | | |
|---|---|---|---|---|
| 5 | 2.4 | 0.3685E-01 | 0.1079E 01 | 0.1747E 01 |
| 6 | 3.0 | 0.6154E-01 | 0.1529E 01 | 0.2422E 01 |
| 7 | 3.6 | 0.9265E-01 | 0.2031E 01 | 0.3186E 01 |
| 8 | 4.2 | 0.1297E 00 | 0.2579E 01 | 0.4037E 01 |
| 9 | 4.8 | 0.1720E 00 | 0.3166E 01 | 0.4971E 01 |
| 10 | 5.4 | 0.2189E 00 | 0.3785E 01 | 0.5986E 01 |
| 11 | 6.0 | 0.2692E 00 | 0.4436E 01 | 0.7081E 01 |
| 12 | 6.6 | 0.3223E 00 | 0.5114E 01 | 0.8253E 01 |
| 13 | 7.2 | 0.3771E 00 | 0.5815E 01 | 0.9501E 01 |
| 14 | 7.8 | 0.4329E 00 | 0.6541E 01 | 0.1082E 02 |
| 15 | 8.4 | 0.4889E 00 | 0.7292E 01 | 0.1222E 02 |
| 16 | 9.0 | 0.5444E 00 | 0.8064E 01 | 0.1368E 02 |
| 17 | 9.6 | 0.5988E 00 | 0.8862E 01 | 0.1522E 02 |
| 18 | 10.2 | 0.6516E 00 | 0.9686E 01 | 0.1682E 02 |
| 19 | 10.8 | 0.7022E 00 | 0.1054E 02 | 0.1849E 02 |
| 20 | 11.4 | 0.7503E 00 | 0.1142E 02 | 0.2023E 02 |
| 21 | 12.0 | 0.7954E 00 | 0.1233E 02 | 0.2203E 02 |
| 22 | 12.6 | 0.8372E 00 | 0.1328E 02 | 0.2389E 02 |
| 23 | 13.2 | 0.8752E 00 | 0.1426E 02 | 0.2582E 02 |
| 24 | 13.8 | 0.9091E 00 | 0.1529E 02 | 0.2781E 02 |
| 25 | 14.4 | 0.9385E 00 | 0.1635E 02 | 0.2987E 02 |
| 26 | 15.0 | 0.9631E 00 | 0.1747E 02 | 0.3198E 02 |
| 27 | 15.6 | 0.9825E 00 | 0.1865E 02 | 0.3415E 02 |
| 28 | 16.2 | 0.9964E 00 | 0.1988E 02 | 0.3624E 02 |
| 29 | 18.2 | 0.1357E 01 | 0.2004E 02 | 0.3663E 02 |
| 30 | 20.2 | 0.1635E 01 | 0.2015E 02 | 0.3702E 02 |
| 31 | 22.2 | 0.1836E 01 | 0.2023E 02 | 0.3741E 02 |
| 32 | 24.2 | 0.1965E 01 | 0.2029E 02 | 0.3780E 02 |
| 33 | 26.2 | 0.2027E 01 | 0.2034E 02 | 0.3819E 02 |
| 34 | 28.2 | 0.2018E 01 | 0.2039E 02 | 0.3858E 02 |
| 35 | 30.2 | 0.1932E 01 | 0.2046E 02 | 0.3896E 02 |
| 36 | 32.2 | 0.1749E 01 | 0.2055E 02 | 0.3935E 02 |
| 37 | 34.2 | 0.1447E 01 | 0.2070E 02 | 0.3974E 02 |
| 38 | 36.2 | 0.9997E 00 | 0.2092E 02 | 0.4013E 02 |
| 39 | 38.2 | 0.9013E 00 | 0.2095E 02 | 0.4019E 02 |
| 40 | 40.2 | 0.8024E 00 | 0.2099E 02 | 0.4024E 02 |
| 41 | 42.2 | 0.7030E 00 | 0.2103E 02 | 0.4030E 02 |
| 42 | 44.2 | 0.6031E 00 | 0.2107E 02 | 0.4036E 02 |
| 43 | 46.2 | 0.5030E 00 | 0.2111E 02 | 0.4041E 02 |
| 44 | 48.2 | 0.4025E 00 | 0.2116E 02 | 0.4047E 02 |
| 45 | 50.2 | 0.3019E 00 | 0.2121E 02 | 0.4052E 02 |
| 46 | 52.2 | 0.2013E 00 | 0.2126E 02 | 0.4058E 02 |
| 47 | 54.2 | 0.1006E 00 | 0.2131E 02 | 0.4063E 02 |
| 48 | 56.2 | 0. | 0.2137E 02 | 0.4069E 02 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN. | SET FS,IN. |
|---|---|---|---|---|---|
| 910 | 0.3640E 04 | 0.5485E 00 | 0.3354E 00 | 0.1988E 02 | 0.1493E 01 |

| NNP | DEPTH,FT | U,PSI | SET,IN. | ULTSET,IN |
|---|---|---|---|---|
| 2 | 0.6 | 0.9494E-03 | 0.1433E 00 | 0.2898E 00 |
| 3 | 1.2 | 0.5327E-02 | 0.3784E 00 | 0.6773E 00 |

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| | | | | |
|---|---|---|---|---|
| 4 | 1.8 | 0.1415E-01 | 0.6993E 00 | 0.1164E 01 |
| 5 | 2.4 | 0.2797E-01 | 0.1098E 01 | 0.1747E 01 |
| 6 | 3.0 | 0.4709E-01 | 0.1565E 01 | 0.2422E 01 |
| 7 | 3.6 | 0.7156E-01 | 0.2090E 01 | 0.3186E 01 |
| 8 | 4.2 | 0.1012E 00 | 0.2668E 01 | 0.4037E 01 |
| 9 | 4.8 | 0.1358E 00 | 0.3291E 01 | 0.4971E 01 |
| 10 | 5.4 | 0.1748E 00 | 0.3954E 01 | 0.5986E 01 |
| 11 | 6.0 | 0.2177E 00 | 0.4654E 01 | 0.7081E 01 |
| 12 | 6.6 | 0.2638E 00 | 0.5386E 01 | 0.8253E 01 |
| 13 | 7.2 | 0.3125E 00 | 0.6145E 01 | 0.9501E 01 |
| 14 | 7.8 | 0.3631E 00 | 0.6933E 01 | 0.1082E 02 |
| 15 | 8.4 | 0.4148E 00 | 0.7747E 01 | 0.1222E 02 |
| 16 | 9.0 | 0.4669E 00 | 0.8585E 01 | 0.1368E 02 |
| 17 | 9.6 | 0.5188E 00 | 0.9450E 01 | 0.1522E 02 |
| 18 | 10.2 | 0.5697E 00 | 0.1034E 02 | 0.1682E 02 |
| 19 | 10.8 | 0.6192E 00 | 0.1126E 02 | 0.1849E 02 |
| 20 | 11.4 | 0.6665E 00 | 0.1220E 02 | 0.2023E 02 |
| 21 | 12.0 | 0.7112E 00 | 0.1318E 02 | 0.2203E 02 |
| 22 | 12.6 | 0.7528E 00 | 0.1419E 02 | 0.2389E 02 |
| 23 | 13.2 | 0.7909E 00 | 0.1524E 02 | 0.2582E 02 |
| 24 | 13.8 | 0.8249E 00 | 0.1633E 02 | 0.2781E 02 |
| 25 | 14.4 | 0.8544E 00 | 0.1746E 02 | 0.2987E 02 |
| 26 | 15.0 | 0.8791E 00 | 0.1864E 02 | 0.3198E 02 |
| 27 | 15.6 | 0.8987E 00 | 0.1987E 02 | 0.3415E 02 |
| 28 | 16.2 | 0.9126E 00 | 0.2115E 02 | 0.3624E 02 |
| 29 | 18.2 | 0.1279E 01 | 0.2133E 02 | 0.3663E 02 |
| 30 | 20.2 | 0.1562E 01 | 0.2145E 02 | 0.3702E 02 |
| 31 | 22.2 | 0.1767E 01 | 0.2155E 02 | 0.3741E 02 |
| 32 | 24.2 | 0.1898E 01 | 0.2162E 02 | 0.3780E 02 |
| 33 | 26.2 | 0.1958E 01 | 0.2168E 02 | 0.3819E 02 |
| 34 | 28.2 | 0.1941E 01 | 0.2174E 02 | 0.3858E 02 |
| 35 | 30.2 | 0.1839E 01 | 0.2182E 02 | 0.3896E 02 |
| 36 | 32.2 | 0.1636E 01 | 0.2194E 02 | 0.3935E 02 |
| 37 | 34.2 | 0.1316E 01 | 0.2211E 02 | 0.3974E 02 |
| 38 | 36.2 | 0.8627E 00 | 0.2235E 02 | 0.4013E 02 |
| 39 | 38.2 | 0.7778E 00 | 0.2239E 02 | 0.4019E 02 |
| 40 | 40.2 | 0.6924E 00 | 0.2243E 02 | 0.4024E 02 |
| 41 | 42.2 | 0.6065E 00 | 0.2247E 02 | 0.4030E 02 |
| 42 | 44.2 | 0.5204E 00 | 0.2251E 02 | 0.4036E 02 |
| 43 | 46.2 | 0.4339E 00 | 0.2256E 02 | 0.4041E 02 |
| 44 | 48.2 | 0.3473E 00 | 0.2260E 02 | 0.4047E 02 |
| 45 | 50.2 | 0.2605E 00 | 0.2265E 02 | 0.4052E 02 |
| 46 | 52.2 | 0.1736E 00 | 0.2270E 02 | 0.4058E 02 |
| 47 | 54.2 | 0.8679E-01 | 0.2276E 02 | 0.4063E 02 |
| 48 | 56.2 | 0. | 0.2281E 02 | 0.4069E 02 |

| NCT | TIME,DAYS | U OF DM | U OF FS | SET DM,IN. | SET FS,IN. |
|---|---|---|---|---|---|
| 1001 | 0.4004E 04 | 0.5837E 00 | 0.3730E 00 | 0.2115E 02 | 0.1660E 01 |

<u>Program Listing</u>

16. A listing for program PROCON is given below.

```
2376T 01 03-18-75 13.278

C PROCON ONE-DIM LAYERED CONSOLIDATION OF DREDGED MATERIAL
C SP EXP; CONTAINMENT AREA
  DIMENSION U(51),V(51),UINIT(51),X(51),IX(52,3),S(51),SU(51),
& NOUT(30),PERM(10),CV(10),DMV(10),NTIMIN(30)
  CALL ATTACH(02,"/JATA;",3,0,ISTAT,)
  REWIND 02
  READ 99
  99 FORMAT(30H
  CALL ATTACH(01,"/DATA;",1,0,ISTAT,)
   15 FORMAT(V)
  CALL SREAD(1,N,2)
  READ(39,15)NTIME,(NOUT(I),I=1,NTIME)
  CALL DETACH(39,;)
  READ(01,15)NSTAT,NNP,NMAT,DT
  READ(01,15)NSTAT,SPGR,DDEN,AMV,BMV,ACV,BCV,APER,BPER
  CALL SREAD(1,N,2)
  READ(39,15)NDROP,(NTIMIN(I),I=1,NDROP)
  CALL DETACH(39,;)
  READ(01,15)NSTAT,NDNP,NOPT,MOPT,LORT
  READ(01,15)NSTAT,(PERM(I),I=2,NMAT),(CV(I),I=2,NMAT)
  READ(01,15)NSTAT,(DMV(I),I=2,NMAT)
  BDEN=DDEN-DDEN/SPGR
  NEL=NNP-1
  IF(MOPT.EQ.1)GO TO 33
  WRITE(02,34)
  34 FORMAT(//,40H NCT   TIME,DAYS   U OF DM     U OF FS
& 26H   SET DM,IN.  SET FS,IN.   ,/)
  33 CONTINUE
  N=1
  5 READ(01,15)NSTAT,M,X(M)
  DF=M+1-N
  IF(M-N)1,2,3
  1 WRITE(02,2034)
  2034 FORMAT("ERROR IN NODE=",I5)
  GO TO 5
  3 DX=(X(M)-X(N-1))/DF
  4 CONTINUE
  X(N)=X(N-1)+DX
  2 CONTINUE
  N=N+1
  IF(M-N)6,2,4
  6 IF(NNP+1-N)7,7,5
  7 CONTINUE
  N=0
  14 READ(01,15)NSTAT,M,(IX(M,I),I=1,3)
  16 N=N+1
  IF(M-N)17,17,18
  18 IX(N,1)=IX(N-1,1)+1
  IX(N,2)=IX(N-1,2)+1
  IX(N,3)=IX(N-1,3)
  17 CONTINUE
  IF(M-N)20,20,16
```

```
      20 IF(NEL-N)21,21,14
      21 CONTINUE
      CALL DETACH(01,ISTAT,)
C     INITIAL EFFECTIVE PORE PRESSURE
      DO 35 I=1,NNP
      S(I)=0.
      SU(I)=0.
      U(I)=0.
      UINIT(I)=0.
      35 V(I)=0.
      IF(LOPT.EQ.0)GO TO 36
      CALL ATTACH(03,"/EXCESS!",3,0,ISTAT,)
      REWIND 03
      IF(LOPT.EQ.1)GO TO 36
      DO 37 I=NDNP,NNP
      READ(03,15)U(I)
      37 CONTINUE
      REWIND 03
      36 CONTINUE
      NUMDR=0
      NCT=0
      TIME=0.
      P=0.
      100 IF(NCT.EQ.0)GO TO 40
      IF(NCT.EQ.NOUT(NTIME))GO TO 999
      NFDR=NTIMIN(NUMDR)
      IF(NCT.EQ.NFDR)GO TO 40
      GO TO 200
      40 NUMDR=NUMDR+1
      NACTNP=NDNP-NUMDR+1
       JJ=NACTNP
       DH=X(JJ)-X(JJ-1)
       DO 45 I=NACTNP,NNP
      D=X(I)-X(I-1)
      D=12.*D
      IF(NCT.EQ.0)GO TO 46
      MTYP=IX(I-1,3)
      IF(I.EQ.NACTNP)GO TO 47
      GO TO 48
       47 P=(BDEN*DH)/288.
      GO TO 49
      48 IF(I.GT.NDNP)GO TO 44
       P=P+(BDEN*DH)/144.
      49 DMV(1)=AMV+BMV*ALOG10(P)
       44 SSU=(BDEN*DH*D*DMV(MTYP))/144.
      SS=(UINIT(I)-U(I))*D*DMV(MTYP)
      SU(I)=SU(I)+SSU
      S(I)=S(I)+SS
       46 U(I)=U(I)+BDEN*DH/144.
      V(I)=U(I)
      UINIT(I)=U(I)
     45 CONTINUE
```

```
      IF(NOPT.EQ.0)GO TO 200
      U(NNP)=0.
      V(NNP)=0.
      200 NCT=NCT+1
      TIME=TIME+DT
      SET=0.
      SETU=0.
       P=(BDEN*DH)/288.
      CV1=ACV+BCV*ALOG10(P)
      PER1=APER+BPER*ALOG10(P)
       PER1=10.**PER1
      DO 60 I=NACTNP,NEL
      D=X(I)-X(I-1)
      D1=X(I+1)-X(I)
      K=IX(I-1,3)
      K1=IX(I,3)
      IF(I.GT.NDNP)GO TO 80
       P=P+(BDEN*D)/144.
      CV(1)=ACV+BCV*ALOG10(P)
      PER2=APER+BPER*ALOG10(P)
      PERM(1)=10.**PER2
       R=PER1/PERM(K1)
      D=12.*D
      D1=12.*D1
      DR=(2.*CV1*DT)/(D+D1)
      CV1=CV(1)
      PER1=PERM(1)
      GO TO 55
      80 R=PERM(K)/PERM(K1)
      D=12.*D
      D1=12.*D1
      DR=(2.*CV(K)*DT)/(D+D1)
      55 IF(R-1.)61,62,61
      62 U(I)=(DR*((U(I-1)/D)-(U(I)-U(I+1))/D1)+U(I))/(1.+(DR/D))
      GO TO 60
      61 F=(D1/(D+R*D1))*(1.-R)
      SI=U(I+1)+(U(I+1)-V(I-1))*F
      U(I)=(DR*((U(I-1)/D)-(U(I)-SI)/D1)+U(I))/(1.+(DR/D))
      60 CONTINUE
      IF(NOPT.EQ.1)GO TO 74
      U(NNP)=U(NEL)
      V(NNP)=U(NNP)
      74 CONTINUE
      DO 90 I=1,NNP
      90 V(I)=U(I)
      DO 300 KK=1,NTIME
      J=NOUT(KK)
      IF(NCT.EQ.J)GO TO 301
      300 CONTINUE
      GO TO 100
      301 IF(MOPT.EQ.0)GO TO 311
      WRITE(02,395)
```

```
395 FORMAT(//,45H NNP DEPTH,FT U,PSI SET,IN, ULTSET,IN)
311 CONTINUE
DEPTH=0.
 JJ=NACTNP
 DH=X(JJ)-X(JJ-1)
DO 350 M=NACTNP,NNP
MTYP=IX(M-1,3)
D=X(M)-X(M-1)
DEPTH=DEPTH+D
D=12.*D
IF(M.EQ.NACTNP)GO TO 370
GO TO 380
 370 P=(BDEN*DH)/288.
GO TO 390
380 IF(M.GT.NDNP)GO TO 360
 P=P+(BDEN*DH)/144.
390 DMV(1)=AMV+BMV*ALOG10(P)
360 SEU=(BDEN*DH*D*DMV(MTYP))/144.
SE=(UINIT(M)-U(M))*D*DMV(MTYP)
SET=SET+SE+S(M)
SETU=SETU+SEU+SU(M)
IF(MOPT.EQ.0)GO TO 401
WRITE(02,400)M,DEPTH,U(M),SET,SETU
400 FORMAT(I5,F5.1,3E12.4)
401 CONTINUE
IF(M.EQ.NDNP)GO TO 305
IF(M.EQ.NNP)GO TO 306
GO TO 350
305 DSETU=SETU
DSET=SET
UDAV=SET/SETU
GO TO 350
306 FSETU=SETU-DSETU
FSET=SET-DSET
UAV=FSET/FSETU
IF(UAV.LT.0.0001)UAV=0.
350 CONTINUE
IF(MOPT.EQ.0)GO TO 333
WRITE(02,330)
330 FORMAT(/,40H NCT TIME,DAYS U OF DM U OF FS
& 26H SET DM,IN. SET FS,IN. ,/)
333 CONTINUE
WRITE(02,320)NCT,TIME,UDAV,UAV,DSET,FSET
320 FORMAT(I5,5E12.4)
GO TO 100
999 CONTINUE
ENDFILE 02
IF(LOPT.EQ.0)GO TO 888
DO 850 I=1,NNP
WRITE(03,860)U(I)
860 FORMAT(E15.5)
850 CONTINUE
ENDFILE 03
888 STOP
END
```

# APPENDIX C: NOTATION

| | |
|---|---|
| $a$ | Constant (Equation 20), and radius of particle (Equation A1) |
| $a_v$ | Coefficient of compressibility |
| $A_{ca}$ | Area of containment area |
| $A_p$ | Projected area of the particle in the direction of flow |
| $\overline{A}$ | Parameter of settling velocity theory |
| $B$ | Bulking factor |
| $B_o$ | Parameter |
| $\overline{B}$ | Parameter of $1 - n$ of settling dredged material |
| $c_v$ | Coefficient of consolidation |
| $C$ | Concentration per volume of the solid particles |
| $C_D$ | Drag coefficient |
| $d$ | Diameter of the sediment particles |
| $dH$ | Increment of depth |
| $dS$ | Settlement for increment of depth $dH$ |
| $dx$ | Vertical increment of dimension |
| $dx\ dy\ dz$ | Change in volume |
| $dy, dz$ | Horizontal increment of dimension |
| $d_{50}$ | Average particle diameter |
| $D$ | Initial depth of slurry |
| $D_{dm}$ | Total depth in containment area available for dredged material and ponded water |
| $e$ | Void ratio (Equation 3), and void ratio at time $t$ (Equation 4) |
| $e_o$ | Initial void ratio for consolidation |
| $e_{os}$ | Initial void ratio for sedimentation |
| $e'_{os}$ | Initial void ratio after discharge of effluent water |
| $e_\infty$ | Ultimate void ratio following sedimentation in theory by Bosworth |
| $e_I$ | Void ratio at the inflection point of a sedimentation curve |
| $E$ | Efficiency |
| $\overline{E}$ | Volume ratio, $1 + e$ |
| $F$ | Function of coefficient of compressibility |

| | |
|---|---|
| $F_i$ | Fraction of solids in input slurry by weight |
| $F_i'$ | Fraction of solids in input slurry by weight after discharge of effluent water |
| $F_o$ | Fraction of solids in discharge effluent by weight |
| $g$ | Acceleration of gravity |
| $G$ | Function of coefficient of permeability (Equation 20), and specific gravity of liquid (Equation A7) |
| $G_s$ | Specific gravity of solids |
| $h$ | Increment of sediment depth deposited during a time interval |
| $H$ | Thickness of sediment (Equation 5) or depth and length of drainage path (Equation 10) |
| $H_d$ | Accumulated depth of dredged material after $N$ disposal operations |
| $H_o$ | Original depth of soil layer |
| $H_{DM}$ | Depth of dredged material |
| $H_F$ | Depth of foundation soil |
| $k$ | Coefficient of permeability |
| $\underline{k}$ | Sedimentation constant in theory by Bosworth |
| $k_{DM}$ | Coefficient of permeability of dredged material |
| $k_F$ | Coefficient of permeability of foundation soil |
| $K$ | Correction factor in settling velocity theory |
| $\overline{K}$ | Parameter in consolidation theory by Long |
| $L$ | Length |
| $m$ | Rate of deposition (Equation 11), and a soil layer (Equation 18) |
| $m_v$ | Coefficient of volume change |
| $M$ | Mass |
| $n$ | Porosity |
| $n_i^t$ | Void ratio at location $i$ and time $t$ |
| $N$ | Total number of dredging operations to fill containment area to capacity |
| $P$ | $n^{4.5}$ |
| $q_e$ | Volume of solids entering an infinitesimal volume per unit time |
| $Q_d$ | Rate of discharge of effluent water from the containment area |

| | |
|---|---|
| $Q_{in}$ | Rate of input of dredged material into the containment area |
| $Q_{in\ situ}$ | Rate of input at in situ water content |
| $q_{\ell}$ | Volume of solids leaving an infinitesimal volume per unit time |
| $R$ | Drag on the particle |
| $S$ | Change in height (Equation 7), and settlement (Equation 9) |
| $t$ | Time (Equation 3), and incremental change in time (Equation A14) |
| $t'$ | Time for sedimentation after termination of a single dredging operation |
| $t_d$ | Time required for discharge of ponded water |
| $t_{do}$ | Time required for single dredging operation |
| $t_t$ | Total time for the dredging operation and sedimentation of dredged material |
| $T$ | Time factor |
| $u$ | Total pore water pressure |
| $u_e$ | Excess pore water pressure |
| $u_{e_i}^t$ | Excess pore water pressure at point $i$ and time $t$ |
| $u_{e_{max}}$ | Maximum excess pore water pressure |
| $u_{eo}$ | Initial excess pore water pressure |
| $u_{et}$ | Total excess pore water pressure |
| $\bar{U}$ | Average degree of consolidation |
| $v$ | Velocity of the liquid phase |
| $v_s$ | Velocity of solid particles |
| $V_{ca}$ | Volume needed in the containment area to accommodate the volume of dredged material |
| $V_d$ | Volume of water discharged from the containment area |
| $V_{ic}$ | Total initial capacity of containment area |
| $V'_{ic}$ | Capacity of containment area needed for a single dredging operation |
| $V_{in}$ | Volume of in situ sediment to be dredged |
| $V_s$ | Volume of solids |
| $V_w$ | Volume of water |
| $w_{ca}$ | Water content of sediment in the containment area |
| $w_{in}$ | Water content of in situ material to be dredged |

| | |
|---|---|
| $W_{sca}$ | Initial weight of solids in the containment area |
| $W'_{sca}$ | Weight of solids in the containment area following discharge of effluent water |
| $W_{sd}$ | Weight of solids discharged from the containment area |
| $x$ | Vertical dimension (Equation 6) and incremental change in depth (Equation A14) |
| $\alpha$ | Parameter of new method for determining sedimentation |
| $\alpha_o$ | Constant |
| $\gamma_b$ | Submerged unit weight |
| $\gamma_d ca$ | Dry density of sediment in the containment area |
| $\gamma_d in$ | Dry density of the in situ soil |
| $\gamma_d^t$ | Dry density at time $t$ years |
| $\gamma_d^1$ | Dry density after one year |
| $\gamma_w$ | Unit weight of water |
| $\mu$ | Viscosity of the liquid |
| $\pi$ | 3.1416 |
| $\rho$ | Density of liquid phase |
| $\rho_s$ | Density of solid particles |
| $\sigma$ | Applied increment of stress |
| $\bar{\sigma}_v$ | Effective stress in the vertical direction |
| $\tau$ | Parameter of new method for determining sedimentation |

**In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.**


Johnson, Lawrence D

Mathematical model for predicting the consolidation of dredged material in confined disposal areas, by Lawrence D. Johnson. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1976.

1 v. (various pagings) illus. 27 cm. (U. S. Waterways Experiment Station. Technical report D-76-1)

DMRP Work Unit No. 2C08.

Includes bibliography.

1. Consolidation (Soils). 2. Dredged areas. 3. Dredged material. 4. Dredged material disposal. 5. Dredged spoil. 6. Mathematical models. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Technical report D-76-1)

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